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Consumer Cash Usage: A Cross-Country Comparison with Payment Diary Survey Data*

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We measure consumers' use of cash by harmonizing payment diary surveys from seven countries. The seven diary surveys were conducted in 2009 (Canada), 2010 (Australia), 2011 (Austria, France, Germany, and the Netherlands), and 2012 (the United States). Our paper finds cross-country differences—for example, the level of cash usage differs across countries. Cash has not disappeared as a payment instrument, especially for low-value transactions. We also find that the use of cash is strongly correlated with transaction size, demographics, and point-of-sale characteristics such as merchant card acceptance and venue.

JEL Codes: E41, D12, E58.

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1. Introduction

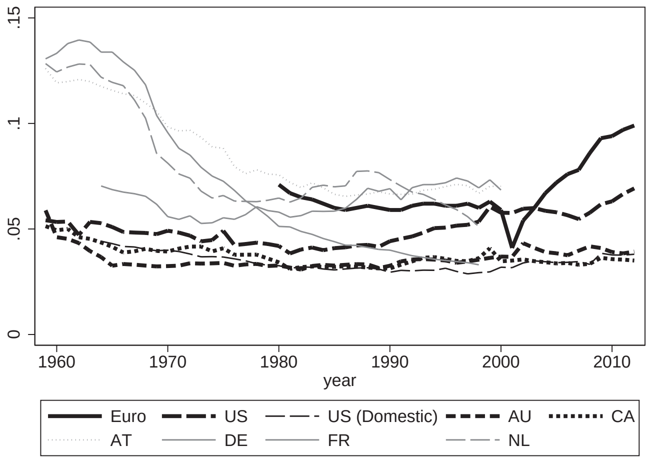
During the past several decades, payment systems worldwide have become increasingly electronic, transformed by innovations in financial markets and information technology—even in less-developed countries that rely heavily on mobile phones; see Jack, Suri, and Townsend (2010) for a discussion of Kenya. Now, these electronic innovations have spread to private virtual currencies, such as Bitcoin; see European Central Bank (2012) and Velde (2013). During this breathtaking transformation, relatively little research has been done comparing payment systems in different countries since the seminal work of Humphrey, Pulley, and Vesala (1996). In the rare instances where comprehensive data are available for comparison, usually cash is excluded; see the studies by Bolt, Humphrey, and Uittenbogaard (2008) and the Federal Reserve System (2013). However, new research is revealing an emerging consensus that during the transformation of payments from paper to electronics, cash holding and use have not disappeared.[1]

Figure 1 depicts the surprising resilience of cash in the twenty-first century for a select group of industrial countries. In most of

suggestions. Finally, we thank Eugenie Foster of the International Association of Currency Affairs (IACA) for arranging the 2010 IACA meetings in Buenos Aires, Argentina. This venue facilitated early discussions of an international cash comparison. The views expressed are solely those of the authors and not those of the Bank of Canada, De Nederlandsche Bank, the Deutsche Bundesbank, the Federal Reserve Bank of Boston or the Federal Reserve System, the Groupement des Cartes Bancaires, the Oesterreichische Nationalbank, Reserve Bank of Australia, or the Eurosystem. Author contact: Bagnall: Reserve Bank of Australia, 65 Martin Place, Sydney NSW 2000, Australia; Tel.: +61 2 9551 8794; E-mail: BagnallJ@rba.gov.au. Bounie: Telecom ParisTech. 46, rue Barrault Paris Cedex 13, F-75634, France; Tel.: +33 1 45 81 73 32; E-mail: david.bounie@telecom-paristech.fr. Huynh: Bank of Canada, 234 Wellington St., Ottawa, ON K1A 0G9, Canada; Tel.: +1 (613) 782 8698; E-mail: khuynh@bankofcanada.ca. Kosse: De Nederlandsche Bank, P.O. Box 98 1000, AB Amsterdam, The Netherlands; Tel.: +31-(0)20-5242827; E-mail: j.c.m.kosse@dnb.nl. Schmidt: Deutsche Bundesbank, Wilhelm-Epstein-Str. 14, 60431 Frankfurt am Main, Germany; Tel.: +49 (0) 69 9566 3730; E-mail: tobias.schmidt@bundesbank.de. Schuh: Federal Reserve Bank of Boston, 600 Atlantic Avenue, Boston, MA 02210-2204, USA; Tel.: +1 617-973-3941; E-mail: Scott.Schuh@bos.frb.org. Stix: Oesterreichische Nationalbank, POB 61, 1011 Vienna, Austria; Tel.: +43 (0)1 40420 7211; E-mail: helmut.stix@oenb.at.

[1]Examples include Amromin and Chakravorti (2009), Lippi and Secchi (2009), and Evans et al. (2013).

Figure 1. Ratios of Currency in Circulation to Nominal GDP



Sources: Haver Analytics, International Financial Statistics, and authors' calculations.

these countries, the ratios of currency in circulation (CIC) relative to nominal GDP generally declined at least through the 1980s or even early 1990s. Since then, however, these ratios have stayed flat or even increased. Likely, the CIC ratios for the United States (US) and the euro area (euro) have increased considerably because of strong foreign demand for the dollar and the euro; see Fischer, Köhler, and Seitz (2004) and Judson (2012). However, even the estimated domestic U.S. currency ratio has increased since 2000 and its behavior is similar to that of the ratios in the other non-euro countries.[2] The econometric evidence in Briglevics and Schuh (2013b) suggests that some of the recent U.S. increase may be the result of a decline in short-term interest rates to nearly zero. Nevertheless, persistent holding and use of cash in these industrial countries during the spread of electronic alternatives highlights a dire need for

[2]The domestic currency ratio could still be driven by domestic hoarding. One indicator of transaction demand is given by the ratio of medium-denomination bank notes to nominal GDP. Judson (2012) shows that the respective ratio for $20 decreased by half for the United States and Canada since the 1970s but has remained fairly stable over the past ten years.

an updated comparative study of payments that includes the use of cash. Furthermore, evidence on *consumer* holding and use of cash is even rarer.[3]

This paper attempts to fill this gap in the literature by comparing the payment choices of consumers in the seven industrial countries portrayed in figure 1 using a unique and growing data source.[4] The data are collected from large-scale payment diary surveys conducted in Australia (AU), Austria (AT), Canada (CA), France (FR), Germany (DE), the Netherlands (NL), and the United States (US).[5] Consumer payment diaries, which trace back at least to Boeschoten and Fase (1989) and Boeschoten (1992), feature rich information on individual payments collected over a fixed number of days paired with information on the detailed characteristics of individual consumers.[6] Payment diaries require consumers to record their transactions, so they should provide more accurate data than surveys, which rely on consumer recall.

The current paper offers two contributions relative to previous work: (i) a careful, thorough harmonization and analysis of these international diary data; and (ii) an econometric analysis of consumers' use of cash versus non-cash payment instruments that employs the microeconomic data from the payment diaries.

As with most international data, harmonization is essential to be able to make valid and useful cross-country comparisons.[7] Although the diary surveys are similar across countries, direct comparisons of their respective statistics cannot be made without meticulous

[3]An early U.S. example is the Survey of Currency and Transactions Account Usage described in Avery et al. (1986).

[4]Jonker, Kosse, and Hernández (2012) and Arango et al. (2013) provide complementary comparisons of subsets of these seven countries.

[5]The payment diaries from these seven countries do not form an exhaustive list of international sources of consumer payments data. Other sources include Takács (2011), Danish National Bank (2013), and UK Payments Council (2013).

[6]The Austrian National Bank has the longest history of successive diaries in 1995, 2000, 2005, and 2011 starting with Mooslechner and Wehinger (1997).

[7]The efforts to harmonize consumer payment diaries were inspired by international initiatives such as the Penn World Tables (Summers and Heston 1991), International Trade and Foreign Direct Investment (Feenstra et al. 2010), and the European Central Bank's wealth survey project (Eurosystem Household Finance and Consumption Network 2009).

analysis and adjustment of the technical details of the diary survey design and concept definitions. Seemingly minor details, such as the inclusion (or exclusion) of recurring bill payments, can have substantial effects on the resulting statistics. Therefore, we have harmonized the underlying data sources and results from the seven individual country diaries so that the reported figures are comparable. In addition, we have harmonized the definition of sociodemographic variables, perceptions, and point-of-sale (POS) characteristics (e.g., card acceptance and the spending location), which permits a disaggregated view of payment behavior. As a result, the statistics reported in this paper may not coincide exactly with analogous data from national statistics. One factor that cannot be harmonized, however, is the supply of services and providers across the national payment systems. For example, paper checks still are relatively common in France and the United States but not in the other countries. Primarily for this reason, we do not attempt to model specific non-cash payment instruments in each country.

Using the harmonized data, we shed light on two empirical issues. First, we demonstrate the extent of consumer cash holding and use in each of the seven economies. Second, the micro data allow us to discover who uses cash, for which purchases, at which locations, and for what value of payment. These data may help us determine why cash is used and whether or not it is likely to continue to be used in the future.

Our econometric analysis of consumer cash use follows in the tradition of the recent literature that seeks to understand the determinants of consumer payment behavior more broadly. This literature extends back at least to Stavins (2002), who estimated the effects of consumer characteristics such as age, education, and income on consumer use of payment instruments and certain banking practices. More recent papers on this subject, such as Borzekowski, Kiser, and Shaista (2008), Ching and Hayashi (2010), Schuh and Stavins (2010), von Kalckreuth, Schmidt, and Stix (2014b), or Arango, Huynh, and Sabetti (2015), inter alia, add a variety of other explanatory variables to such regressions. Unlike most studies, which use data usually from one country or only a few countries, this harmonized diary database makes it possible to assess the extent to which the determinants of payment choice are specific to a particular country or are more general in nature.[8]

Our econometric analysis is a first step toward what ultimately can be done with the diary data and generates a few notable results. In the logit estimation of cash versus non-cash use, we find a surprising degree of similarity in the significant marginal effects of determinants of payment use across countries, both qualitatively and quantitatively. Not surprisingly, the similarity is stronger for consumer payments made at grocery stores, which presumably are relatively homogeneous payment opportunities across countries in terms of goods, transaction sizes, and merchant acceptance of payments. Much more econometric modeling could be done with this harmonized diary database.

Using comprehensive, cross-country information on cash usage to develop a more refined understanding of consumer payment choices is important for policymakers and academics alike. In recent years, regulation of credit card and debit card interchange fees has come to the forefront in a number of countries. Better insight into consumer behavior is essential for the determination and evaluation of these regulations. The study of cash demand and management also is important for evaluation of the cost of payments,[9] seigniorage revenue, central bank management of currency stocks, and the welfare costs of inflation. The use of payment instruments to access bank accounts is important for understanding bank supervision and regulation, and may provide insights into consumer welfare associated with liquid asset management. The breadth and importance of all of these topics underscore the puzzling deficiency of statistical evidence on cash use by consumers, and the importance of payment diaries as a resource for future research.

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[8]We do not attempt to estimate models of consumer demand for cash, which is the subject of another closely related branch of the literature including Daniels and Murphy (1994), Mulligan and Sala-i-Martin (2000), Attanasio, Guiso, and Jappelli (2002), Bounie and Francois (2008), Lippi and Secchi (2009), and Briglevics and Schuh (2013b). These studies rely on consumer surveys, rather than diaries, to collect cash-related data on consumers, and generally do not attempt to estimate consumer demand for other payment instruments.

[9]Schmiedel, Kostova, and Ruttenberg (2013) provide a summary of the ECB cost study.

The paper is organized as follows. Section 2 presents salient aggregate results regarding the payment behavior in the seven countries, which provide a foundation for the subsequent analysis. Section 3 describes the payment diaries and steps taken to harmonize the database. Section 4 presents the consumer expenditure patterns across countries. Section 5 discusses the various factors that may affect the levels of cash usage across countries. Section 6 presents the estimation results for the econometric models of consumer choice between the use of cash versus non-cash payment instruments and provides robustness analyses. Section 7 provides a discussion on cross-country differences, and section 8 concludes.

2. Salient Results

Table 1 distills our findings concerning the payment structure in each of the seven countries. Although the harmonization of the data sources will be discussed in more detail in section 3, at this point we note that the presented figures include basically all personal payments of respondents made either at a POS, for remote purchases, or in person to other persons. Recurrent transactions (e.g., rent, utility bills) are excluded. Our main findings follow:

- Between 46 percent and 82 percent of the number of all payment transactions are conducted by cash.
- In value terms, differences across countries are stark. AT and DE are cash-intensive countries with a value share of more than 50 percent; in CA, FR, and US, cash payments account for only about one-fourth of the value of transactions.
- The composition of non-cash payments varies substantially across countries. Credit cards are used more frequently in AU, CA, and US than in European countries. Across all countries considered, debit cards are used more frequently than credit cards, with particularly high use in NL. FR and US have a large share in the *other* category. Checks constitute a non-trivial portion in both countries, while prepaid cards are a factor in the US.
- The overwhelming fraction of payments is conducted with only a few payment instruments: the accumulated cash, debit, and

Table 1. Salient Results

	AU	AT	CA	FR	DE	NL	US
Payment Share by Volume							
Cash	0.65	0.82	0.53	0.56	0.82	0.52	0.46
Debit	0.22	0.14	0.25	0.31	0.13	0.41	0.26
Credit	0.09	0.02	0.19	0.01	0.02	0.01	0.19
Total	0.96	0.98	0.97	0.88	0.97	0.95	0.91
Other Most Important Payment Instrument (Share > 5%)	—	—	—	0.09[a]	—	—	—
Payment Share by Value							
Cash	0.32	0.65	0.23	0.15	0.53	0.34	0.23
Debit	0.32	0.25	0.30	0.43	0.28	0.60	0.27
Credit	0.18	0.05	0.41	0.03	0.07	0.04	0.28
Total	0.82	0.95	0.94	0.60	0.89	0.97	0.78
Other Most Important Payment Instrument (Share > 5%)	0.12[b]	—	—	0.30[a]	—	—	0.14[a]
Ownership of Payment Cards							
Debit Share	0.93	0.85	0.97	0.83	0.94	0.99	0.76
Credit Share	0.47	0.24	0.81	0.36	0.33	0.62	0.67
Average Transaction Values							
Cash	15.2	24.7	12.9	10.9	25.0	17.4	17.8
Debit	43.3	55.6	37.6	56.6	75.7	39.1	37.3
Credit	60.0	85.9	64.7	92.5	160.5	95.6	56.4
Acceptance of Alternatives to Cash[c]							
Share	—	0.63	0.73	—	0.57	—	—
Average Cash Balances in Wallet							
Mean	59	148	64	70	123	51	74
Median	32	114	38	30	94	28	37

Notes: Authors' calculations based on questionnaire and diary surveys. Nominal values are expressed in PPP-adjusted USD. PPP exchange rates are taken from the OECD: http://www.oecd.org/std/prices-ppp/.
[a]Checks.
[b]Internet/telephone banking.
[c]Acceptance as perceived by consumers.

credit share is greater than 95 percent for AU, AT, CA, DE, and NL, and greater than 88 percent for FR and US.

The major question that emerges from these findings is how the levels of cash use in the various countries can be explained. As a first attempt, table 1 summarizes information on three indicators about market structure. The results show the following:

- Payment card ownership (especially debit card ownership) is high in all countries. However, there are large cross-country differences with respect to the dissemination of credit cards. This suggests that the use of cash may be correlated with the level of card ownership.
- Another indication about market structure can be obtained from average transaction values. In all seven countries, the average value of cash transactions is lower than the average value of card transactions. This result is consistent with prevalent transaction-size models (i.e., Whitesell 1989; Bouhdaoui and Bounie 2012). Notably, in countries where cash is used relatively more frequently, the average card transaction value is higher than it is in countries where there is more intensive use of cards.
- The acceptance of payment cards by merchants differs across countries. There is limited evidence from the surveys, but available evidence for AT, CA, and DE indicates there is a correlation with cash usage.
- Survey responses suggest that cash balances are substantially higher for AT and DE than for the other countries. This result corresponds with the importance of cash for payments in these countries. This correlation may not be causal and there may be a simultaneity in cash management and payment behavior. For example, the level of cash balances might affect consumers' use of cash, but similarly, the use of cash may also be a determinant of the amount of cash consumers carry.

We will use the above findings to delve deeper into the levels in cash use across countries. To get a better grasp, we will also analyze cash use by looking at (i) the expenditure structure in the various countries, (ii) whether cash usage differs across transaction types and POS characteristics (transaction value, type of expenditure, acceptance), and (iii) whether the use of cash varies across sociodemographic factors. Similarly, we further assess the interrelation between cash holdings and payment behavior by delving deeper into cash management practices of consumers. As a case in point, table 1 highlights that all "non-cash-intensive" countries have a rather similar median cash balance of about 30 purchasing power parity (PPP)-USD. This suggests that consumers behave rather similarly in different countries. We will further exemplify and analyze this issue by looking at withdrawals and other aspects of cash management behavior.

3. Consumer Payment Diaries—Validity and Harmonization

This section provides a short overview of the methodological features and key survey outcomes of the payment diaries included in the cross-country comparison. We will start with a more general discussion about the value of payment diary data, by contrasting diary studies with classical ways of collecting information, such as questionnaire surveys or macro data analyses. The section concludes with a few remarks on the harmonization steps necessary to create comparable data sets.

3.1 Consumer Payment Diaries

Several types of data can be used to assess consumers' use of payment instruments. First, official transaction records of banks, card processors, or retailers can be employed. The advantage of these data is that they are based on observed behavior and they provide a good basis for examining aggregate changes in payment use over time. However, often such data do not allow for an in-depth analysis of behavior at the consumer level. Some data are proprietary, so individual behavior cannot be tracked. Scanner data do not usually provide information about the consumer and are focused on only a certain portion of consumer behavior (e.g., grocery purchases); see Cohen and Rysman (2013).

Therefore, payment studies often have recourse to consumer survey data. Here a distinction can be made between data collected through consumer questionnaires versus data collected through consumer payment diaries. The advantage of questionnaires is that the burden on the respondent is limited to the time needed for completing the questionnaire at one moment in time; diaries, in contrast, require respondents to report information over a number of days. While the consumer questionnaire generates data that allow for thorough analyses of general behavioral patterns as well as the underlying drivers, it is less suitable for analyzing the specificities of individual payments. For example, surveys may serve as a valuable tool for measuring the adoption of payment instruments by consumers, while diaries are better for assessing their actual use.[10]

Collecting payment data through diaries has thus become popular in recent years.[11] The main benefits of using diary data—in particular, in combination with questionnaire data—are obvious. Foremost, as consumers are stimulated to record with a minimum of delay after each particular transaction, the probability of transactions being omitted or erroneously reported is lower than for questionnaire surveys. Payment diaries also allow for the collection of many details of individual transactions, such as the payment amount, the payment location, the acceptance of non-cash payments, and surcharging, which enable better understanding of the factors that drive consumer heterogeneity in payment behavior.

Insofar as payment diaries record cash balances over time, they also allow for an examination of the interaction between payment choice and cash management. When conducted for several days, a temporal sequence of actual payments and cash withdrawals can be created, which is useful for understanding within-consumer heterogeneities in payment instruments usage.

[10]In particular, when asking about individual payments, questionnaires may suffer from "recall bias" or under-reporting of payments due to incomplete recall. Frequent and low-value payments are especially sensitive to being omitted; see Jonker and Kosse (2013).

[11]Collecting data using diaries has a long history in official statistics on expenditure; see McWhinney and Champion (1974). Earlier general surveys about payments were conducted by Avery et al. (1986) and Boeschoten (1992). Mooslechner and Wehinger (1997) conducted a payment diary in Austria in 1996.

3.2 Validity of Seven Payment Diaries

Our study uses payment diaries that were conducted independently in each country and hence were not harmonized. Differences pertain to the number of recorded days (from one to eight days), the mode of data collection (paper versus online), the scope of transactions covered (e.g., recurrent and remote transactions), and the level of detail regarding transaction characteristics (table 2).[12] To account for these differences, we put a lot of effort into the harmonization of the variables and concepts, and we are confident that the level of comparability is high enough to conduct our cross-country analysis. The next subsections discuss similarities and differences as well as the harmonization steps undertaken.

Despite the advantages of diary surveys described above, the question arises as to the representativeness of recorded transactions. Under-reporting is one issue, as illegal transactions and transactions in the realm of the shadow economy will likely not be covered. But even for everyday expenditures, we do not know how well respondents record their transactions.

To ensure the efficacy of the seven payment diaries, we compare the diary outcomes to aggregate expenditure data from national accounts statistics. For this reason, we extrapolate the survey outcomes by multiplying the average daily diary expenditure by 365 to obtain an annual figure. This value is compared with the average annual value of expenses as reported by the Organisation for Economic Co-operation and Development (OECD), deducting expenses for housing, water, electricity, and gas.[13]

The results of this exercise are reported in the last row of the top panel of table 2. For all diaries, the ratio of the extrapolated diary outcomes to the aggregate OECD POS consumption figures ranges from 0.72 to 1.16. Note that certain deviations are to be expected, as both the diary data and the data provided by the OECD are

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[12]The literature has shown that the specific design of a diary may affect the quality of the collected data; e.g., Sudman and Ferber (1971), Crossley and Winter (2012), and Jonker and Kosse (2013).

[13]We focus on the average annual expenses by the adult population only, since the samples used in the diary surveys also only targeted residents aged between eighteen and seventy-five years.

Table 2. Survey Design Summary

	AU	AT	CA	FR	DE	NL	US
Year	2010	2011	2009	2011	2011	2011	2012
Month(s)	Oct–Nov	Oct–Nov	Nov	Oct–Nov	Sep–Nov	Sep	Oct
Data Collection	Paper	Paper	Online Paper	Paper	Paper	Online Phone	Online Paper
Sampling Frame	18+	15+	18–75	18+	18+	18+	18+
Diary Length (Days)	7	7	3	8	7	1	3
Respondents	1,240	1,165	3,283	1,106	2,098	7,175	2,468
Total Transactions	18,110	12,970	15,832	10,759	19,601	11,877	13,942
Diary-to-Aggregate-Expenditure Ratio	1.11	0.92	0.99	0.88	0.97	1.16	0.72
Macroeconomic Aggregates							
Short-Term Nominal Interest Rate	5.0	1.5	0.4	1.5	1.5	1.6	0.2
Core Inflation	2.5	2.4	1.1	1.2	1.0	1.9	1.9
Real GDP Growth	2.5	1.3	–1.4	1.5	2.5	1.1	2.0
Output Gap	–1.1	–0.6	–3.0	–0.8	0.3	–0.5	–3.4
Unemployment Gap	–0.1	–0.1	1.0	0.2	–0.9	0.6	2.0

Notes: For these diary-to-aggregate-expenditure ratios, we calculate the total annual per-person expenditure in local currency, by multiplying the average per-person per-day expenditure figure from each diary with 365 days. We compare this estimated annual consumption figure with national accounts data from the OECD website. We start with the time series labeled "P31NC: Final consumption expend. of res. households on the territory and abroad" and subtract "P33: Final consumption expenditure of resident households abroad." We also subtract "P31CP040: Housing, water, electricity, gas and other fuels" to arrive at a concept of consumption expenditure more comparable to what we have in the diaries. The diaries do not cover recurrent payments, and most of the payments for housing and utilities are recurring. Finally, we divide the calculated consumption expenditure by the total adult population, implying that we assume that the responses to our diaries do not include consumption expenditure for minors. To harmonize the transaction values in this study, we use PPP-adjusted USD. PPP exchange rates are taken from the OECD: http://www.oecd.org/std/prices-ppp/. Macroeconomic aggregates are taken from the following OECD Stat Extracts: Short-term interest rate: http://www.oecd.org/std/. Core inflation: http://stats.oecd.org/index.aspx?queryid=26661. Output gap: *OECD Economic Outlook*, Volume 2014, Issue 1, Annex Table 10. Latest versions available at http://www.oecd.org/eco/outlook/economic-outlook-annex-tables.htm. GDP growth: http://stats.oecd.org/index.aspx?queryid=26674. Unemployment: http://stats.oecd.org/index.aspx?queryid=36324. NAIRU: http://stats.oecd.org/Index.aspx?DataSetCode=EO95_INTERNET.

based on sampling-based survey estimates, and, hence, are subject to a certain degree of error. Also, due to differences in classifications, the diaries and national account figures are likely to differ regarding the sectors and types of payment included.

Therefore, we interpret the ratios, which all vary around 1.00, as evidence that all individual surveys perform rather well in capturing the actual expenses made in these countries. Moreover, all countries undertook a number of plausibility checks. These comprised either comparison with population figures (if available; e.g., the average number and value of debit card payments or automated teller machine (ATM) withdrawals) or with other sources (such as other market research reports). Some countries could refer to earlier payment diary or questionnaire studies and check their stability over time.

One factor that may adversely affect our efforts to harmonize the diaries is cross-country variation in the state of business-cycle conditions.[14] The lower panel of table 2 summarizes these conditions by reporting standard macroeconomic aggregates for each country at the time its diary was fielded (between 2009 and 2012). Short-term nominal interest rates were relatively low, in the range of 0.2 percent (US) to 1.6 percent (NL) with the exception of AU, which was 5.0 percent. All of the countries had reasonably low core inflation, ranging from 1.0 percent (DE) to 2.5 percent (AU). Most countries were growing in terms of real GDP except for Canada, which declined 1.4 percent and had a –3.0 percent output gap. The United States, though expanding (2.0 percent real GDP growth), also had a large negative output gap (3.4 percent). Not much is known yet about the cyclical properties of consumer payment choice because of a general lack of time-series data. Following the financial crisis, U.S. consumers significantly increased their use of cash and decreased their use of credit cards (Schuh and Stavins 2014), suggesting there may be some cyclical variation, but we do not have enough data or business cycles to formally adjust the diary responses. The reader may wish to bear in mind that the results for each country may be influenced by the macroeconomic conditions

[14]We thank an anonymous referee for pointing out this observation to us.

prevailing at the time of the survey—for example, the output gaps in CA and US.

3.3 Similarities

The seven diary surveys share a number of similarities (see table 2). First, all seven diaries collect data on POS transactions. Each diary attempts to record non-business-related personal expenditures of the respondent (whether for the respondent or for other people). Second, the information collected for each transaction is similar. All respondents were asked to record (i) the date (and sometimes even the time), (ii) the transaction value, (iii) the payment instrument used, and (iv) the merchant's sector where the purchase occurred. AT, CA, DE, and NL respondents were asked to assess whether the purchase could have been paid using payment instruments other than the one actually used. For cash withdrawals, all diaries collected information on the location (and in some cases the timing) as well as on the amount of the withdrawal. Each diary furthermore contained questions on consumers' cash balances either before the first recorded transaction or for their typical average cash holdings.

Third, the seven diary studies are similar in that they were all conducted at the end of the year, i.e., between September and November. The fieldwork was conducted in 2009 (CA), 2010 (AU), 2011 (AT, FR, DE, and NL), and 2012 (US).

Fourth, the seven diaries are similar with respect to the population being surveyed. Most targeted residents were between the ages of eighteen and seventy-five years, although some diaries were also distributed among children and people over seventy-five years of age. However, as discussed above in the expenditure ratio, all the analyses presented in this paper focus only on the payments made by adults. Finally, all diary surveys yielded data sets containing more than 10,000 transactions.

3.4 Differences

Several differences among the diaries should be kept in mind when interpreting the results. First, some diaries asked respondents to fill out the diary using paper and pencil (AU, AT, DE, and FR). US and CA relied on a mix of paper and online questionnaires. For NL, information was collected via an online tool or by phone, if desired. Also, a difference relates to the selection of respondents. Most countries used random stratified or clustered sampling techniques, but they differed with respect to the frame from which the respondents were selected. For CA, NL, and US, for instance, respondents were randomly selected from an existing panel of consumers who regularly participate in surveys.

Online data-collection methods and online panels may be sensitive to biases when particular population groups are excluded from participation because of not having access to the Internet, and when the persons who do participate behave differently than those who do not; see Bethlehem (2008). Yet, given the high Internet penetration for CA, NL, and US, the potential biases caused by the use of online methods and online panels can be expected to be limited. Jonker and Kosse (2013) demonstrate for NL that drawing respondents from an online panel does not introduce pro-electronic biases reflected in an over-estimation of card usage. Moreover, in order to prevent any such biases, all panelists for US were provided with a computer or with Internet access.

Second, differences exist with respect to the length of the diaries, as follows: one day (NL), three days (CA, US), seven days (AT, AU, and DE), and eight days (FR). Research by McWhinney and Champion (1974), Ahmed, Brzozowski, and Crossley (2006), Jonker and Kosse (2013), and Schmidt (2014) investigate the possibility that longer diaries may lead to survey fatigue (i.e., under-reporting of expenditures), especially for small-value transactions. Despite these differences and their potential consequences, we believe that, due to their richness, the seven data sets are well suited for answering the main questions of this paper. Moreover, as will be discussed below, we conducted some robustness checks that confirmed that the differences in diary length do not sizably affect our overall findings and conclusions.

3.5 Harmonization

We undertook the following harmonization steps to create seven data sets that are mutually comparable. In particular:

- We distilled all payments from persons aged eighteen years and older.
- We only consider the payments made at the POS; payments for remote purchases via mail order, the telephone, or the Internet; and in-person person-to-person payments. Recurrent transactions (e.g., rents, utility bills) are excluded.

Also, we conducted a number of harmonization steps with respect to the reported results on card acceptance at the POS, consumer preferences, and type of purchases made. The results with respect to the type of purchases, however, should only be taken as a rough indicator, due to the large national differences in the number and size of categories used.[15] Finally, we harmonized the definitions and categories of the various sociodemographic characteristics (e.g., income, education).

4. Expenditure Patterns

Table 3 reports summary statistics of the total structure of recorded payments and thereby of expenditures of consumers.[16] It shows that the structure of payments is very similar across countries with respect to the day of the week, time of day, and payment channel. As expected, Sunday is the day with the lowest share of transactions, although some cross-country differences are discernible. For example, the Sunday share is slightly higher for AU and US, which is reasonable given cultural differences in store opening hours. About one-third of transactions are conducted before noon, and two-thirds

[15]Harmonization difficulties arose mainly because of (i) national differences in how the information was collected (from only a few broad categories of sectors in some countries to very detailed lists in other countries); (ii) differences in the categorization of expenditures (e.g., some countries recorded expenditures in restaurants and hotels in one category; other countries recorded hotel expenditures with other services), and (iii) differences in the structure of retail shops (e.g., in some countries newspapers and tobacco can be bought in grocery shops; other countries have small special shops for these expenditures).

[16]Note that these are consumer expenditures and not consumption.

Table 3. Structure of Consumer Payments

	AU	**AT**	**CA**	**FR**	**DE**	**NL**	**US**
Transactions Volume PPD							
Mean	2.1	1.6	1.7	1.5	1.4	1.8	1.6
Median	1.9	1.4	1.3	1.3	1.3	1.0	1.3
Expenditures PPD							
Mean	63	50	50	43	48	52	62
Median	41	34	28	27	35	20	31
Distribution of Transaction Values							
25th Percentile	5.1	7.1	4.4	2.9	7.0	5.1	12.3
Median	12.0	16.7	11.9	12.5	17.8	11.3	22.7
75th Percentile	25.3	37.3	30.3	35.0	42.6	28.4	39.8
Transactions Volume Shares							
Days of the Week:							
Monday	0.14	0.15	0.11	0.12	0.14	0.12	0.16
Tuesday	0.13	0.14	0.15	0.15	0.15	0.13	0.16
Wednesday	0.14	0.14	0.17	0.15	0.15	0.13	0.16
Thursday	0.16	0.15	0.19	0.16	0.15	0.19	0.13
Friday	0.16	0.16	0.14	0.16	0.17	0.18	0.13
Saturday	0.16	0.16	0.15	0.17	0.17	0.17	0.14
Sunday	0.11	0.09	0.09	0.08	0.08	0.07	0.12
Time of Day:							
AM	—	0.38	0.33	—	—	—	0.31
PM	—	0.62	0.67	—	—	—	0.69
Payment Channel:							
In Person	0.952	0.985	1.000	0.954	0.977	1.000	0.936
Internet/Mobile	0.044	0.011	—	0.015	0.015	—	0.051
Mail-Order/Phone	0.003	0.004	—	0.017	0.009	—	0.013
Sectoral Composition:							
Groceries	0.31	0.42	0.33	0.46	0.46	0.44	0.20
Gasoline	0.07	0.06	0.08	0.03	0.08	0.09	0.08
Semi-durables	0.18	0.13	0.15	0.12	0.06	0.18	0.12
Services	0.15	0.09	0.04	0.14	0.07	0.09	0.30
Restaurants/Drinks	0.21	0.17	0.22	0.09	0.16	0.13	0.27
Other	0.07	0.14	0.19	0.15	0.16	0.08	0.03

Notes: Authors' calculations based on diary surveys. PPD refers to per person per day. Nominal values are expressed in PPP-adjusted USD. To harmonize the transaction values in this study, we use PPP-adjusted USD. PPP exchange rates are taken from the OECD: http://www.oecd.org/std/prices-ppp/.

after. Finally, in-person transactions make up the vast majority of payments.[17]

With respect to the type of purchase or the sectoral composition, keeping the harmonization difficulties in mind, we find that groceries account for the majority of transactions in all countries (except for US). The share of grocery expenditures is quite similar for AT, FR, DE, and NL. Also, the gas station expenditure share, which arguably constitutes the most homogeneous type of expenditure, is similar across countries. These results provide evidence that some aggregate shopping patterns are similar across the seven countries examined.

More importantly, the diaries are also informative regarding other payment characteristics about which relatively little is known, at least in a comparative perspective. This brings us to our first fact:

FACT 1. *The structure of consumer payments is generally similar across most of the countries with respect to the number and the value of transactions: (i) Consumers conduct only a few payment transactions per day and (ii) most consumer expenditures are relatively small in value.*

The mean number of transactions per person per day (PPD) varies from 1.4 to 2.1 transactions across countries. The median person, who arguably is more robust to outliers, conducts only 1.3 transactions for CA, FR, DE, and US, and 1.4 transactions for AT. The median amount spent PPD varies across countries, ranging from 20 to 41 PPP-USD.

Analyzing individual transactions provides another angle from which to view the data. Table 3 reports the quartiles of transaction values. This analysis shows that the median transaction amount is around 12 PPP-USD for AU, CA, FR, and NL. For AT, DE, and US, the value is higher, at 17 to 22 PPP-USD. We also find that 75 percent of all recorded transactions are lower than 25 to 40 PPP-USD.

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[17]For AU and US, Internet/mobile payments at the POS account for a volume share that is higher than 4 percent, while in all other countries it is almost negligible.

5. Cash Usage: Descriptive Evidence

Table 1 documented the outstanding importance of cash in all countries. In this section, we focus on the use of cash in terms of transaction size, cash balances, sociodemographics (income, education, age, and consumer preferences), cash card ownership, and POS characteristics (acceptance of payment cards and type of economic activity). The selection of these factors rests on previous literature that has mostly been confined to the analysis of single countries.[18] Note that the descriptive statistics presented in this section provide only a first indication of the potential correlation with cash usage, disregarding all other factors. A final answer on the role of each of the selected factors in explaining consumers' cash usage can only be provided after controlling for the other variables using multivariate econometric estimations. These estimates are completed in section 6.

5.1 Transaction Size

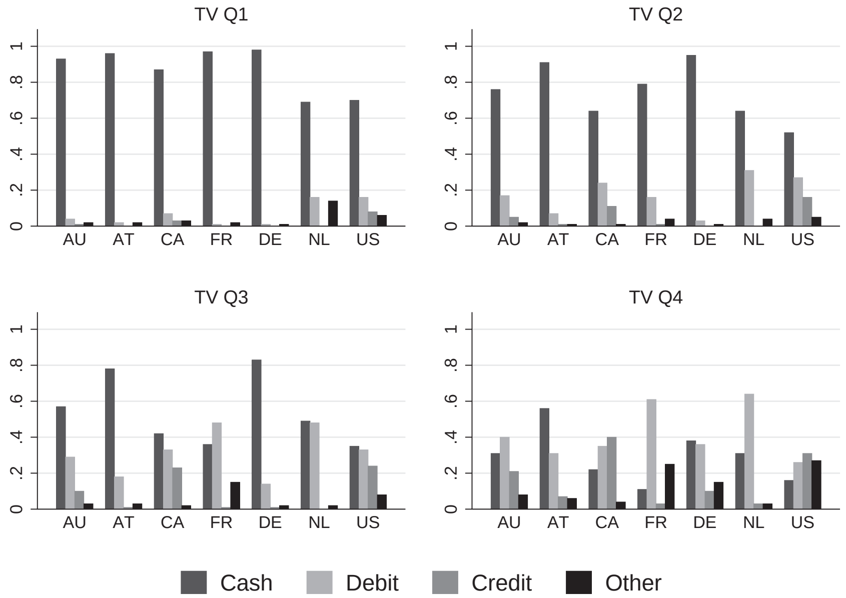
Numerous previous papers have shown that transaction size is highly correlated with the choice of payment instruments (e.g., Klee 2008; Bouhdaoui and Bounie 2012; von Kalckreuth, Schmidt, and Stix 2014a; Arango, Huynh, and Sabetti 2015). Our analysis substantiates these findings.

FACT 2. *The use of cash decreases with transaction size. In all countries, cash is predominant for the smallest 50 percent of transactions. For the largest 25 percent of transactions, the use of payment instruments is very heterogeneous across countries.*

Figure 2 depicts the payment instrument shares for cash, debit, credit, and other payment instruments for each transaction value quartile. This figure confirms the dominance of cash for low transaction values in all countries. In the first transaction value quartile, debit plays only a minor role for CA, NL, and US, while credit is

[18]One shortcoming of our analysis is that our data cannot establish the causal link between payment choice and card pricing (e.g., Borzekowski, Kiser, and Shaista 2008; Simon, Smith, and West 2010). Moreover, whenever we analyze POS characteristics, we assume that these are fixed.

Figure 2. Value Share of Cash by Transaction Value Quartiles



Source: Authors' calculations based on diary surveys.

used only materially for CA (share of 3 percent) and US (share of 6 percent). Other payment instruments have a notable share for low-value transactions only for NL (14) and US (6 percent). For all countries, we find that the cash share is higher than 50 percent up to the median transaction value. In the third quartile, the dominance of cash fades. In this transaction value range, however, cash has a materially higher share than debit or credit in three countries and a share that is about equal to the share of debit for CA, FR, NL, and US. In the fourth quartile, the full heterogeneity across countries becomes evident: (i) the importance of credit card payments for AU, CA, and US relative to other countries, (ii) the importance of checks for FR and US, and (iii) the relative importance of debit versus credit in all European countries.

5.2 Cash Balances

Withdrawal innovations such as ATM terminals have affected the demand for cash. For instance, Alvarez and Lippi (2013) show that free and random withdrawal opportunities can give rise to a precautionary motive for holding cash, meaning that agents withdraw cash even if they have some cash on hand. Several empirical studies suggest that higher cash holdings are correlated with higher use of cash in payments; see Bouhdaoui and Bounie (2012), Arango et al. (2013), Eschelbach and Schmidt (2013), and Arango, Huynh, and Sabetti (2015). Our findings provide support for a relationship between cash usage and cash balances.

FACT 3. *Austria and Germany, relative to other countries, are cash intensive, with large cash balances and large average withdrawal amounts.*

Table 4 reports statistics on individuals' cash management patterns. The average cash balances (M) for AT (148 PPD-USD) and DE (123 PPD-USD) are two times greater than those in other countries (from 51 for NL to 74 PPD-USD for US). These statistics are in line with the greater use of cash in payments for AT and DE, where the share of cash by volume exceeds 80 percent. It reaches a maximum of just 65 percent in other countries. As a consequence, the mean of the ratio M/e, where e denotes daily expenditure, varies from 1.5 for AU to 4.8 for AT. The gaps between countries persist even if we abstract from extreme values: the median equals 0.6 for US, while it reaches 3.4 for AT. The extent to which the suggested relationship between cash balances and cash usage is causal remains unclear. That is, the level of cash balances might affect consumers' use of cash, but, similarly, the use of cash may determine the amount of cash that consumers carry. Hence, it is not clear whether cash management causes cash usage or vice versa.

Cash is obtained from ATMs, bank tellers, and other sources (family, retail stores' cashback, etc.). Except for US, the main source of cash is the ATM; the share of people withdrawing at least once a month from ATMs exceeds 70 percent in all countries. However, the mean number of monthly ATM withdrawals greatly varies across

Table 4. Cash Management

	AU	AT	CA	FR	DE	NL	US
Cash Balances							
In the Wallet (M)	59[a]	148	64	70	123	51[a]	74
Mean M/e	*1.48*	*4.78*	*4.38*	*4.13*	*4.15*	*2.87*	*2.44*
Median M/e	*0.69*	*3.36*	*1.01*	*1.30*	*2.61*	*1.00*	*0.62*
Withdrawals (Number per Month)							
ATM	—	3.48	4.98	3.70	3.08	2.45	1.31
Teller	—	1.07	1.83	2.21	0.99	0.02	0.65
Other Sources	—	1.31	4.05	2.09	0.70	0.40	3.29
Share of Respondents Withdrawing							
ATM (at Least once a Month)	—	0.79	0.73	0.95	0.85	—	0.69
Teller (at Least Once a Month)	—	0.28	0.41	0.70	0.22	—	0.41
Other Source (at Least Once a Month)	—	0.11	0.56	0.71	0.03	—	0.92
Average Withdrawal Amount							
ATM (W)	138	224	86	89	256	102	103
Teller	668	511	225	224	539	75	219
Other Sources	51	559	52	122	125	53	95
W/M	*5.80*	*3.86*	*3.77*	*6.25*	*15.96*	*8.71*	*14.05*
Median W/M	*2.33*	*1.42*	*1.67*	*1.72*	*2.11*	*2.50*	*2.31*
Precautionary Balances							
Cash Balance before Withdrawal ($\underline{M}$)	—	58	22	—	43	—	67
Mean $\underline{M}/M$	—	*0.84*	*0.46*	—	*1.66*	—	*2.29*
Median $\underline{M}/M$	—	*0.25*	*0.20*	—	*0.32*	—	*0.73*

Notes: Authors' calculations are based on questionnaire and diary surveys. M/e is the ratio of cash balances to daily expenditures from the diary. All values represent means, unless otherwise indicated. Nominal values are expressed in PPP-adjusted USD. To harmonize the transaction values in this study, we use PPP-adjusted USD. PPP exchange rates are taken from the OECD: http://www.oecd.org/std/prices-ppp/.

[a]Values for AU and NL are from the questionnaire ("typical" average cash balance); all others are from the diary.

countries, from 1.3 for US to 5 for CA. These withdrawal patterns seem to be directly correlated with the typical cash withdrawal amounts at ATMs.[19]

5.2.1 Implications for Inventory Models of Money Demand

The overall picture that emerges from these figures is that respondents in cash-intensive economies do not economize on cash balances by withdrawing more often. Instead, it seems that they prefer to hold higher cash balances. There are several possible reasons for this behavior. One is that AT and DE respondents hold larger cash balances because of the risk that lumpy purchases can only be conducted in cash (Alvarez and Lippi 2013). This would imply that precautionary balances are higher in these two countries than in other countries. However, the evidence is not conclusive. Cash balances at withdrawals are larger for AT and DE than for CA but not larger than for US.

These descriptive statistics can be further exploited to examine the empirical performance of the deterministic inventory theoretical model proposed by Baumol (1952) and Tobin (1956). We focus our discussion on two statistics. The first is the ratio between cash holdings at the time of a withdrawal ($\underline{M}$) and average/median currency holdings (M). This statistic provides a measure of precautionary balances: the higher $\underline{M}/M$, the more precautionary the consumers are. This ratio is zero in the Baumol-Tobin model, as consumers withdraw only when they have depleted their stock of cash. We notice in table 4 that the median of this ratio ranges from 0.20 for CA to 0.73 for US. The data are thus more in line with the dynamic model of cash management suggested by Alvarez and Lippi (2009), who extend the Baumol-Tobin model to a dynamic environment in which consumers face not only costly ATM withdrawals but also random and free ATM cash withdrawal opportunities. More precisely, the model predicts that consumers withdraw cash when

[19] As previously outlined, US stands out in this respect: the share of people obtaining cash from other sources at least once a month (90 percent) is above that of ATMs and tellers (70 percent and 40 percent, respectively), and the withdrawal frequency at these other sources is far above that for ATMs and tellers (3.3 compared with 1.3 for ATMs and 0.7 for tellers).

facing free withdrawal opportunities even if they have some cash on hand, resulting in a positive ratio of $\underline{M}/M$ (with values between zero and one).

The second interesting statistic (W/M) is the ratio between the average withdrawal amount at the ATM (W) and the average currency holdings (M), which is also related to the precautionary motive ($\underline{M}/M$). Since withdrawals only happen when cash balances reach zero, in the Baumol-Tobin model W/M is equal to 2. With random free withdrawals, Alvarez and Lippi (2009) show that this ratio will be below 2. The higher the number of free cash withdrawals relative to the overall number of withdrawals, the higher $\underline{M}/M$ and the lower W/M—consumers take advantage of the free random withdrawals regardless of their cash balances, which decreases the level of cash withdrawals. As free withdrawal opportunities relative to the overall number of withdrawals increase, $\underline{M}/M$ becomes greater than 0 (and lower than 1) while W/M tends from 2 to 0, implying a negative correlation between these ratios.

In the data, we find that the median of this ratio lies between 1.42 for AT and 2.31 for US. The data are in line with the prediction of Alvarez and Lippi (2009) regarding the level of W/M in three countries where W/M is found to be lower than 2 (AT, CA, FR). However, the finding of ratios above 2 for four countries is neither compatible with Baumol-Tobin nor with Alvarez and Lippi (2009). Also, if we analyze the values across countries, no negative correlation between these two ratios is discernible. Overall, these findings, if taken at face value, would question deterministic and dynamic models of demand for cash.

However, we treat the results merely as indicative because work which goes beyond the scope of this paper would be necessary to obtain a valid structural comparison across countries. First, consumers have several withdrawal sources, and it is neither obvious how an average withdrawal amount should be computed if several withdrawal sources are used nor how much we can rely on survey information on withdrawal sources that are only rarely used on average, i.e., cashback in Germany or via teller in Netherlands. In the face of this difficulty, we have opted for a pragmatic approach and have used the average withdrawal amount at the ATM as our measure of W. Second, the model of Alvarez and Lippi (2009) makes predictions about the cross-sectional variation across households, while we extend this to a comparison across countries. Institutional, regulatory, and market differences (e.g., density of ATMs, pricing, daily withdrawal limits, etc.) might confound our results. Finally, the dynamic model of cash demand abstracts from precautionary strategies related to consumers' long-term cash management that could induce a ratio W/M greater than 2. One needs to make sure that these considerations do not play a role.

5.3 Sociodemographic Characteristics

This section presents evidence on cash usage along sociodemographics characteristics, and we inquire into consumers' preferences by analyzing survey evidence on perceptions of cash.

5.3.1 Age, Income, and Education

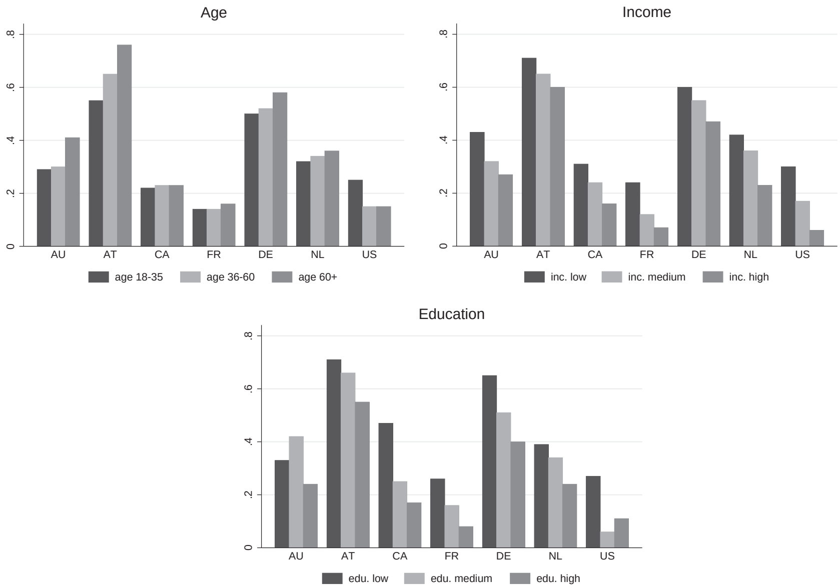
FACT 4. *Cash usage decreases with education and income, but varies across age categories.*

The role of age is of interest because one could argue that the enduring importance of cash could be due to habit persistence. Indeed, previous literature indicates that older people hold and use more cash, while young consumers are more likely to use new payment technologies (e.g., Daniels and Murphy 1994; Boeschoten 1998; Carow and Staten 1999; Stavins 2002; Hayashi and Klee 2003).

Our results in figure 3 reveal that older people use significantly more cash than younger people except for US, where younger individuals use more cash than older individuals. These figures regarding age do not control for differences in expenditure patterns or other personal characteristics; for example, younger consumers may buy different products and/or services and at different venues than older individuals. Therefore, a final answer on the role of age can only be given with estimations that control for these other variables, which will be the focus of the next section.[20]

[20]Von Kalckreuth, Schmidt, and Stix (2014a) find no evidence in favor of strong habit persistence. Instead, they attribute higher cash usage of older people to their differential characteristics (e.g., lower opportunity costs of time or lower income).

Figure 3. Value Share of Cash by Age, Income, and Education



Notes: The graphs depict the shares of cash (in value terms) in percentage for the respective subgroup. Authors' calculations are based on harmonized diary surveys.

Income and education have been cited in the literature as important factors, with cash usage declining with higher income and education (e.g., Arango, Huynh, and Sabetti 2015 for CA; von Kalckreuth, Schmidt, and Stix 2014b for DE; and Schuh and Stavins 2010 and Cohen and Rysman 2013 for US). Figure 3 confirms differences along income terciles, with less cash usage by higher-income respondents. Even stronger differences are found along education. Notably, these differences pertain to all analyzed countries: for DE and CA, the difference in the value share of cash between low education and high education is more than 26 percentage points, while in the remaining countries this difference ranges from 9 to 18 percentage points.[21]

[21]In many respects, these findings mirror the pattern observed for card ownership, which tends to vary along the same sociodemographic lines

Recent work by von Kalckreuth, Schmidt, and Stix (2014a) finds that cash is used to monitor expenditures. In particular, their prediction is that cash will be used for this purpose by individuals who face financial constraints and who have difficulties with other monitoring techniques (such as online accounts). The pattern of results obtained for income and education is in line with this proposition.[22]

5.3.2 Consumer Preferences

One could argue that consumers are using cash because they have no choice; e.g., because payment cards are not accepted or for reasons of costs, safety, or convenience. We can analyze this issue by looking at consumers' ratings of certain payment instrument attributes, which can be viewed as broad proxies for consumer preferences and which have been found to affect payment choice (e.g., Borzekowski, Kiser, and Shaista 2008; Ching and Hayashi 2010; Schuh and Stavins 2010; Arango, Huynh, and Sabetti 2015).

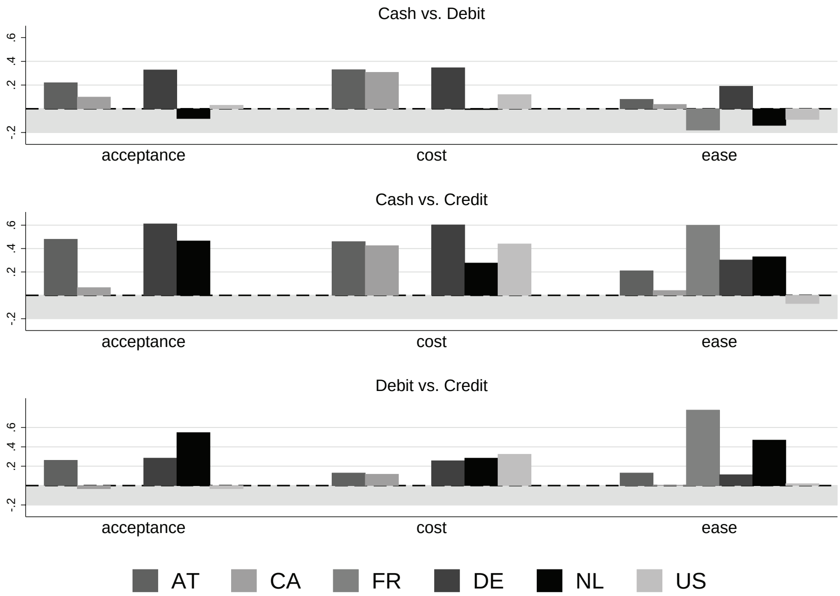
To a varying degree, the seven diaries contain information on preferences that we have attempted to harmonize. The harmonization was difficult because the different diary surveys described and asked about preferences in different ways. Moreover, responses were measured in different ways, with some countries using Likert scales and others binary responses. In the face of these obstacles, we were able to successfully harmonize only responses concerning the relative perceived acceptance, cost, and ease of use of cash. Figure 4 shows a normalized comparison of consumers' ratings of cash versus debit.[23] The depicted measures are scale free, with a positive (negative) value implying that cash is rated better (worse) than debit (a value of zero means that cash is rated the same as debit). Similarly, we show results of a comparison of cash with credit and of debit with credit.

(table 6). However, the case of NL, where debit card ownership does not vary across income or education while the cash shares do, suggests that income and education exert an autonomous effect on cash usage that is independent of card ownership.

[22]The role of debit cards for spending restraint has been recently analyzed by Fusaro (2013).

[23]See Jonker (2007) and Arango, Huynh, and Sabetti (2015) for a description of the normalization. Variables are defined in table 13 in the appendix.

Figure 4. Perceptions of Cash



Notes: The figure shows normalized perceptions of cash relative to debit and credit. A positive (negative) value indicates that cash is perceived better (worse) than the respective payment card. Due to differences in the wording of survey questions, the harmonization is only approximate. Values for acdeptance and costs are not available for FR. For DE, values are taken from the 2008 payment diary. Authors' calculations are based on questionnaire and diary surveys.

FACT 5. *Cash is generally valued highly by consumers for its perceived acceptance, costs, and ease of use.*

Concerning consumer perceptions of acceptance, we can compare results from five countries. For AT, CA, and DE, cash is rated higher than debit. For US, cash is rated the same as debit, and for NL, cash is rated worse than debit. For CA and US, we find that results concerning cash versus debit and cash versus credit are very similar, mirroring that both cards are perceived to have a similar acceptance. In the other countries, credit cards are seen as worse than debit cards, corresponding with the authors' perception of the acceptance of credit cards in countries such as AT, DE, and NL.

With respect to perceived cost, we find that cash is rated better than debit for AT, CA, DE, and US, and for NL it is rated similarly. Again, the difference is more pronounced in favor of cash when it comes to a comparison of cash to credit. Finally, regarding the ease of use, debit is rated higher for AT, CA, and DE, while it is rated lower than cash for FR, NL, and US.

Overall, this evidence suggests that cash usage by consumers is not the sole result of a lack of alternatives. To the contrary, cash is valued by consumers because it is perceived more positively than, or as positively as, credit and debit cards with respect to cost. Also, the assessment shows that in particular in countries with relatively high cash use, ease of use may be an important driver.

5.4 Card Ownership

Cash usage may be influenced by differences in the dissemination and use of payment cards.

FACT 6. *Whereas the levels of card ownership differ across countries, overall card ownership is rather high. Consumers only use a few payment instruments alongside cash.*

Table 5 shows that in each country the vast majority of consumers hold payment cards: For AT, with its high cash share, we observe the lowest card dissemination share of 86 percent. For NL, virtually all consumers are in possession of a payment card.

The most striking difference in card ownership can be seen in the dissemination of credit cards. Table 6 presents disaggregated evidence on card ownership by sociodemographics, showing that differences in credit card ownership prevail along all age, income, and educational groups. These differences suggest that there are factors related to the market structure that affect credit card dissemination.

There are significant differences in the number of cards owned or used (multi-homing).[24] CA and US consumers possess, on average,

[24]Rysman (2007) discusses the issue of multi-homing (that is, respondents' practice of holding or using more than one payment card). In our analysis, we focus on card use on the extensive margin (number of cards), not the intensive margin (how much the card is used).

Table 5. Card Ownership and Multi-homing

	AU	AT	CA	FR	DE	NL	US
Share of Respondents With:							
Payment Card	0.95	0.86	0.99	0.92	0.94	1.00	0.88
Debit Card	0.93	0.85	0.97	0.90	0.94	0.99	0.76
Credit Card	0.47	0.24	0.81	0.31	0.33	0.62	0.67
Number of Payment Cards in Possession							
Mean	1.93	1.77	3.51	1.61	1.85	1.63	4.23
Median	2.00	1.00	3.00	1.00	1.00	2.00	3.00
Number of Payment Instruments Used in Diary							
Mean	2.23	1.75	1.79	2.37	1.88	1.56	2.28
Median	2.00	2.00	2.00	2.00	2.00	1.00	2.00
Share of Respondents Who Revolve or Overdraft							
Revolvers	0.29	—	0.26	—	—	—	0.33
Overdraft	—	0.33	—	—	—	—	0.28

Notes: "Payment Card" is defined as those persons with either a debit or a credit card. Authors' calculations are based on questionnaire and diary surveys. "Revolvers" are those who do not pay off their total credit card balances each month and incur interest/finance charges. "Overdraft" refers to persons who at least sometimes overdraw their checking account.

3.5 and 4.2 payment cards. For all other countries, the respective value is below 2. The median number of payment cards is 3 for CA and US, 2 for AU and NL and only 1 for AT, DE, and FR.

Table 5 also presents evidence on the number of payment instruments used in the diary period. Our findings indicate that the median consumer uses two payment instruments (including cash) over the diary recording period.[25] Although these results are influenced by the length of the diary period, it suggests that the median consumer uses only a few payment instruments alongside cash, which

[25] For NL the median is one payment instrument, which is explained by the fact that respondents only recorded their payments for one day.

Table 6. Card Ownership by Sociodemographics

	AU	AT	CA	FR	DE	NL	US
Debit Card Ownership by Sociodemographics							
Age:							
18–35	0.96	0.95	0.97	0.91	0.96	1.00	0.77
36–60	0.94	0.89	0.98	0.91	0.95	0.99	0.79
60+	0.88	0.69	0.94	0.86	0.91	0.99	0.69
Education:							
Low	0.94	0.79	0.89	0.81	0.86	0.99	0.71
Medium	0.86	0.91	0.98	0.90	0.98	0.99	0.86
High	0.91	0.96	0.97	0.96	0.99	0.99	0.80
Income:							
Low	0.88	0.78	0.96	0.83	0.89	0.98	0.62
Medium	0.95	0.90	0.97	0.93	0.96	0.99	0.82
High	0.94	0.93	0.97	0.96	0.97	0.99	0.82
Credit Card Ownership by Sociodemographics							
Age:							
18–35	0.33	0.21	0.76	0.25	0.31	0.60	0.52
36–60	0.57	0.28	0.84	0.36	0.43	0.62	0.69
60+	0.46	0.20	0.83	0.29	0.24	0.62	0.84
Education:							
Low	0.48	0.13	0.62	0.22	0.16	0.44	0.56
Medium	0.41	0.31	0.77	0.31	0.39	0.55	0.81
High	0.45	0.42	0.91	0.36	0.68	0.75	0.92
Income:							
Low	0.27	0.11	0.64	0.23	0.20	0.36	0.36
Medium	0.53	0.20	0.84	0.32	0.27	0.60	0.75
High	0.54	0.42	0.95	0.52	0.54	0.86	0.91

Notes: Payment card is defined as either a debit or credit card. Authors' calculations are based on diary and questionnaire surveys.

is in line with the results of Cohen and Rysman (2013) using a data set that follows consumers over a much longer period of time.[26]

[26]Table 5 provides evidence on how certain consumers use their cards, i.e., it compares the share of revolvers in US, AU, and CA with the share of persons with overdrafts on their checking accounts for US and AT. Interestingly, all shares are

Table 7. Perceived Acceptance by Transaction Value

	AT	CA	DE
Quartile 1	0.48	0.53	0.28
Quartile 2	0.63	0.71	0.48
Quartile 3	0.68	0.80	0.69
Quartile 4	0.75	0.89	0.87
Overall	0.63	0.73	0.57

Note: The table shows the share of transactions in a given transaction value quartile for which respondents answered that cards were accepted.

5.5 POS Characteristics

Finally, we discuss two types of POS characteristics: (i) card acceptance at the POS, and (ii) the type of economic activity in which transactions occur.

5.5.1 Card Acceptance

FACT 7. *Higher usage of cash is associated with lower levels of card acceptance at the POS.*

The role of card acceptance at the POS can be approached by using direct survey evidence for AT, CA, and DE. In particular, the respective payment diaries recorded whether a transaction could have been made in cashless form. On the basis of this information, we can analyze whether high cash usage is attributable to insufficient payment card acceptance. When interpreting results, however, it should be kept in mind that they are based on the subjective assessment of respondents.

Table 7, which tabulates the consumer's self-stated acceptance of cards at the POS by transaction values, confirms that the acceptance

roughly around 30 percent, even in AT with little credit card use (disregarding measurement difficulties). This result implies that AT consumers use the overdraft facility on their checking account to obtain credit, whereas consumers in the English-speaking countries use their credit cards. Short-term credit could also be obtained with deferred debit cards. However, we do not have comparable information on these types of cards.

of payment cards is much lower for small-value amounts than for large-value amounts. For transaction values in the first quartile, DE stands out with low acceptance. Furthermore, a comparison across countries indicates that (i) CA has the highest acceptance values in each quartile, and (ii) the difference, interestingly, is not strong for higher transaction amounts relative to AT and DE. This evidence is roughly consistent with cash usage. Note again that these descriptive statistics assume all other factors to be fixed. Therefore, to analyze the real effect of card acceptance, econometric analyses will be used in section 6 to account for all other potential factors.

5.5.2 Type of Purchase

FACT 8. *Cash usage varies across types of purchases and venues.*

The diaries allow the analysis of cash usage in different sectors/for different types of expenditures. We have calculated payment instrument shares for cash, debit, and credit for all sectors, summarized in table 8. Given country-specific differences in industry sector definitions, we stress that harmonization is incomplete, particularly for services and "other sectors," so results should be taken with caution.

Cross-country differences in payment patterns across different sectors could be driven by differences in transaction values, card acceptance, or behavioral patterns, or by cultural differences. Accordingly, figure 5 depicts three sectors that we consider interesting with regard to these factors.[27]

First, we suspect that card acceptance at gas stations is almost universal, or at least high in all countries. At the same time, the typical expenditure value is roughly equal in size across countries. This implies that an analysis of cash usage at gas stations should give an indication of the role of acceptance and transaction sizes in explaining the levels of cash usage. That is, if acceptance and transaction sizes were the only factors driving payment behavior, we would expect to find fairly equal levels of cash usage in gas stations

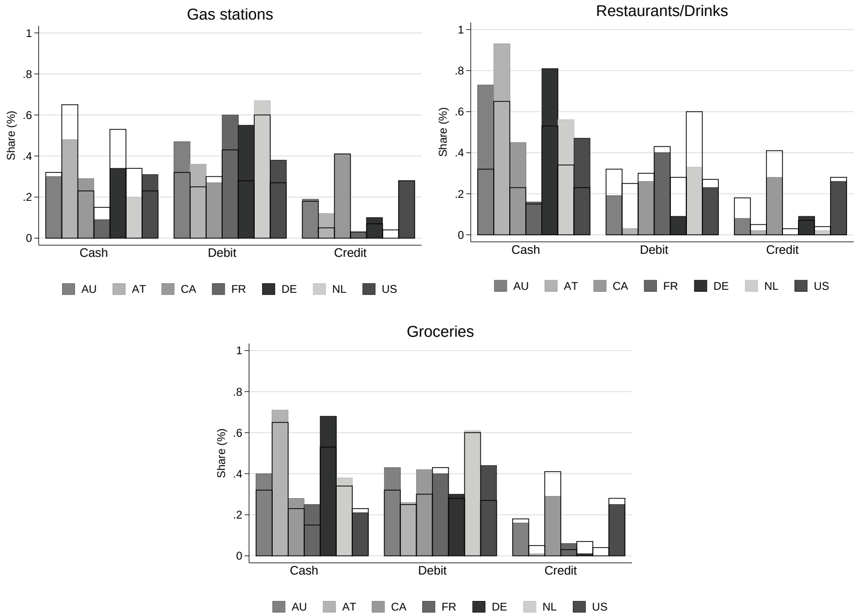
[27]Note that the FR share does not add up to 1 since checks have a non-trivial share.

Table 8. Payment Instrument Value Shares by Type of Purchase

	Groceries	Gasoline	Semi-Durables	Service	Restaurant/ Drinks	Other
Cash						
AU	0.40	0.30	0.21	0.29	0.73	0.21
AT	0.71	0.48	0.43	0.69	0.93	0.78
CA	0.28	0.29	0.12	0.11	0.45	0.24
FR	0.25	0.09	0.09	0.12	0.16	0.12
DE	0.68	0.34	0.26	0.56	0.81	0.42
NL	0.38	0.20	0.27	0.36	0.56	0.39
US	0.21	0.31	0.12	0.16	0.47	0.40
Debit						
AU	0.43	0.47	0.43	0.25	0.19	0.14
AT	0.26	0.36	0.41	0.14	0.03	0.12
CA	0.42	0.27	0.29	0.21	0.26	0.35
FR	0.40	0.60	0.41	0.25	0.40	0.09
DE	0.30	0.55	0.51	0.14	0.09	0.06
NL	0.61	0.67	0.65	0.50	0.33	0.53
US	0.44	0.38	0.32	0.14	0.23	0.08
Credit						
AU	0.16	0.19	0.25	0.24	0.08	0.07
AT	0.01	0.12	0.11	0.04	0.02	0.01
CA	0.29	0.41	0.56	0.54	0.28	0.26
FR	0.06	0.03	0.06	0.01	0.00	0.00
DE	0.01	0.10	0.12	0.13	0.09	0.10
NL	0.00	0.00	0.00	0.01	0.02	0.02
US	0.25	0.28	0.43	0.25	0.26	0.06
Other Payment Instrument (if share > 0.1)						
AU	—	—	0.11	0.21	—	0.58
AT	—	—	—	0.13	—	—
CA	—	—	—	0.14	—	0.15
FR	0.29	0.28	0.44	0.62	0.44	0.79
DE	—	—	0.10	0.17	—	0.43
NL	—	0.12	—	0.13	—	—
US	0.10	—	0.13	0.44	—	0.46

Notes: Authors' calculations are based on diary surveys. Shares are in percent. Sectoral harmonizaton across countries is only approximate.

Figure 5. Value Share of Cash by Location/Activity



Notes: Sectoral harmonization across countries is only approximate. The shaded area shows the shares for the respective location/activity. The transparent bar depicts the shares for all consumer expenditures.

across all countries. Indeed, our results suggest that cross-country differences in cash usage are significantly smaller at gas stations than for all expenditures. In particular, we find that the cash share at gas stations for AT and DE drops significantly relative to the overall cash share.[28] This provides a strong indication of the effects of acceptance and transaction sizes. Despite this finding, we note that sizable differences across countries still prevail, showing that acceptance and sizes are not the only factors driving cash usage.

Second, expenditures at bars and fast food restaurants could be cash intensive due to convenience. Indeed, the descriptive results

[28]Huynh, Schmidt-Dengler, and Stix (2014) find that higher acceptance is correlated with a lower cash share for AT and CA, especially in venues such as gas stations.

show that the cash share for these transactions is substantially higher than the overall cash share for all countries except FR, where checks account for more than 40 percent of the expenditure value share in this sector. It is notable that this can also be observed in countries that have a high card acceptance rate. Again, this result is an indication that consumers differ in their payment behavior depending on the spending location, which is not only to be explained by levels of card acceptance and transaction sizes.

Third, for the grocery sector the cash expenditure share is higher than the average for all countries except US. Interestingly, the debit share is higher for all countries except FR, which has a slight increase in credit cards. We conjecture that this fact is associated with convenience and/or the market structure of the grocery sector. Regarding the first issue, cash could be considered a convenient and fast way to pay for purchases at (small) grocery stores. It might also be correlated with the size of the location and card acceptance. In most European countries, grocery stores are smaller than they are in AU, CA, and US. The grocery sector, often having low margins, might focus on the cost of payments, which could explain the higher usage of debit.

6. Choosing Cash vs. Non-Cash

Ideally, we would like to use the diary data to estimate econometric models to test at least the traditional theoretical models of money demand discussed in section 5, such as the Baumol-Tobin model. In particular, merging the diary micro data would provide an international database that could allow us to quantify international differences in consumer behavior. However, institutional and data limitations prevent us from doing so. Perhaps the most important limitation is the lack of individual-level data on basic core variables, such as interest rates on bank account balances or other liquid assets to proxy for the opportunity cost of cash, which none of the diaries include.[29]

[29] Briglevics and Schuh (2013a) provide an example of the difficulties with obtaining and constructing individual-specific interest rates for use in an econometric Baumol-Tobin model. Huynh, Schmidt-Dengler, and Stix (2014) also

Therefore, this section investigates the choice of using cash versus non-cash in a multivariate setting. We estimate the probability of choosing cash versus non-cash alternatives (either debit or credit) at the POS using the following logit model:

$$U_j^* = X_j\beta + \epsilon_j, \text{ where } j = \text{ Cash, Non-Cash,} \tag{1}$$

where U_j^* is the utility of choice j as a function of observables X_j and a logit error ϵ_j. The variables, X_j, used in the regression are (i) transaction size, (ii) cash balances, (iii) sociodemographic characteristics (age, income, education), (iv) consumer perceptions of ease of use, acceptance, and cost, and (v) POS transaction characteristics (card acceptance and type of purchase). We attempt to harmonize variables for all countries, but there are some differences. Please refer to table 13 in the appendix for the exact list. The sample contains all individuals (also those without payment cards) and all transactions that are conducted using cash, debit, or credit.

The goal of these estimations is twofold. First, we would like to quantify which factors exert an impact on consumers' choice of whether or not to pay in cash, even when controlling for other potential factors. Second, we would like to study whether the use of cross-country data reveals patterns that are common to all countries.

6.1 Results of Logit Regressions

Table 9 reports the marginal effects on the probability of using cash. Our baseline demographic profile is a person aged thirty-five or less that is married, with low education and low income. Overall, the findings are fairly consistent and highlight that demographics play a major role across countries. Even when controlling for transaction size and other characteristics, we find that higher income and higher education are associated with lower cash use.

Regarding age, we find that persons older than thirty-six use significantly more cash than persons younger than thirty-five. Also, the

estimate a Baumol-Tobin model that exploits perceived acceptance of cards at the POS and uses imperfect proxies such as risk of theft and whether respondents revolve on credit card debt.

Table 9. Cash versus Non-Cash Payment Choice (marginal effects)

	AU	AT	CA	FR	DE	NL	US
Medium Income	−0.031	−0.068**	0.021	−0.046**	−0.005	0.006	−0.119***
	(0.017)	(0.024)	(0.021)	(0.017)	(0.011)	(0.016)	(0.02)
High Income	−0.035	−0.067**	0.014	−0.071*	−0.013	−0.009	−0.119***
	(0.019)	(0.025)	(0.027)	(0.031)	(0.012)	(0.016)	(0.025)
Aged 36 to 59	0.071***	0.022	0.041*	0.051**	0.024*	0.043**	0.091***
	(0.017)	(0.018)	(0.019)	(0.017)	(0.01)	(0.016)	(0.023)
Aged Over 60	0.112***	0.057*	0.026	0.042	0.047**	0.061**	0.073*
	(0.027)	(0.024)	(0.031)	(0.028)	(0.018)	(0.02)	(0.029)
Medium Education	−0.04*	0.047	−0.106**	−0.045*	−0.034***	0.005	−0.126**
	(0.02)	(0.029)	(0.039)	(0.022)	(0.01)	(0.016)	(0.047)
High Education	−0.08***	0.011	−0.134***	−0.097***	−0.085***	−0.037**	−0.194***
	(0.015)	(0.022)	(0.04)	(0.027)	(0.014)	(0.014)	(0.046)
Not Homeowner	0.012		0.027				0.01
	(0.014)		(0.022)				(0.021)
Perceptions of:							
Ease	0.123***		0.17***				0.212***
	(0.037)		(0.045)				(0.035)
Cost	−0.046		0.082				0.037
	(0.025)		(0.043)				(0.045)
Security	0.082***		−0.054**				0.064***
	(0.016)		(0.020)				(0.014)
Acceptance	−0.023		−0.08				0.054
	(0.042)		(0.045)				(0.045)
Card Acceptance Share at the POS	−0.104***		−0.48***		−0.105***	−0.546***	
	(0.025)		(0.033)		(0.016)	(0.041	

(*continued*)

Table 9. (Continued)

	AU	AT	CA	FR	DE	NL	US
Cash on Hand	0.002	0.038***	0.005***	0.001***	0.002***	0.006***	0.003***
	(0.001)	(0.01)	(0.001)	(0)	(0.001)	(0.001)	(0.001)
Gasoline	−0.071***	−0.056***	−0.008	−0.161***	−0.098***	−0.046*	0.02
	(0.014)	(0.015)	(0.028)	(0.027)	(0.007)	(0.022)	(0.019)
Semi-durables	−0.047***	−0.039**	−0.036*	−0.098***	−0.082***	0.06***	−0.06**
	(0.012)	(0.012)	(0.017)	(0.016)	(0.008)	(0.014)	(0.019)
Services	0.08**	0.053***	0.031	−0.029*	0.048***	0.054*	0.138***
	(0.025)	(0.012)	(0.029)	(0.014)	(0.011)	(0.027)	(0.019)
Entertainment	0.167***	0.156***	0.109***	−0.098***	0.081***	0.269***	0.09***
	(0.021)	(0.012)	(0.017)	(0.018)	(0.012)	(0.017)	(0.016)
Other (Not Groceries)	0.075***	0.122***	0.084***	0.04**	0.061***	0.161***	0.409***
	(0.017)	(0.023)	(0.018)	(0.015)	(0.01)	(0.022)	(0.04)
TV Q2	−0.168***	−0.248***	−0.254***	−0.241***	−0.117***	−0.11***	−0.178***
	(0.022)	(0.015)	(0.016)	(0.035)	(0.021)	(0.016)	(0.016)
TV Q3	−0.263***	−0.372***	−0.397***	−0.454***	−0.243***	−0.264***	−0.305***
	(0.023)	(0.015)	(0.015)	(0.033)	(0.02)	(0.015)	(0.015)
TV Q4	−0.364***	−0.541***	−0.549***	−0.629***	−0.373***	−0.417***	−0.462***
	(0.023)	(0.013)	(0.015)	(0.028)	(0.02)	(0.016)	(0.017)
Observations	7,841	17,303	12,652	7,549	18,676	8,233	10,671

Notes: The dependent variable takes a value of 1 if a payment is made by cash and 0 if it is made by debit or credit. Results for location (urban/rural), marital status, gender, employment status, and family size are not shown. Variables are defined in table 13 in the appendix. TV Q2, TV Q3, and TV Q4 denote the second to fourth quartile of transaction values. We cluster standard errors at the person level. Standard errors are in parentheses and the 1, 5, and 10 percent levels of significance are denoted by ***, **, and *, respectively.

results provide support for a certain habit persistence in some countries (AT, AU, DE, NL), where cash use increases homogeneously with age: people aged sixty and older are more likely to use cash than people between the ages of thirty-six and fifty-nine.

For three countries that collected data on consumer perceptions regarding payment instruments (AT, CA, and US), the perceived ease of using cash was highly significant and positive. This shows that consumers who rate cash high with regard to ease of use conduct more cash transactions. The perceptions regarding security were different, positive versus negative, between AT and CA. The other perceptions with respect to cost and overall acceptance were not significant. These results are in line with previous research; see Schuh and Stavins (2010), von Kalckreuth, Schmidt, and Stix (2014b), and Arango, Huynh, and Sabetti (2015).

The strongest effect on consumers' choice between cash and non-cash was obtained for transaction values, where the estimation results confirm that the probability of using cash decreases homogeneously with the transaction value quartile. These results hold across all countries. In the fourth transaction value quartile, the probability of using cash is lower by 42 (NL) to 63 percentage points (FR) relative to the first transaction value quartile.

The results also confirm an independent effect of purchase location/type of purchase. The baseline category is a durable purchase in the lowest transaction value category. For expenditures at gas stations and for purchases of semi-durables, the marginal effects were universally negative (with the exception of NL), while for services, entertainment, and groceries they were positive. These results confirm previous results that were based on data from single countries (e.g., Klee 2008; Cohen and Rysman 2013).

Another finding of the logit model is that people who hold higher cash balances on average use cash more often than people with lower cash balances. Note, however, that we treat this as indicative only because of the likely presence of reverse causality.[30] Although we

[30]Applying an instrumental-variable approach that is common to all countries was impossible, because the survey questionnaires differed too much across countries. Omitting cash balances from the regressions, however, does not affect the other findings.

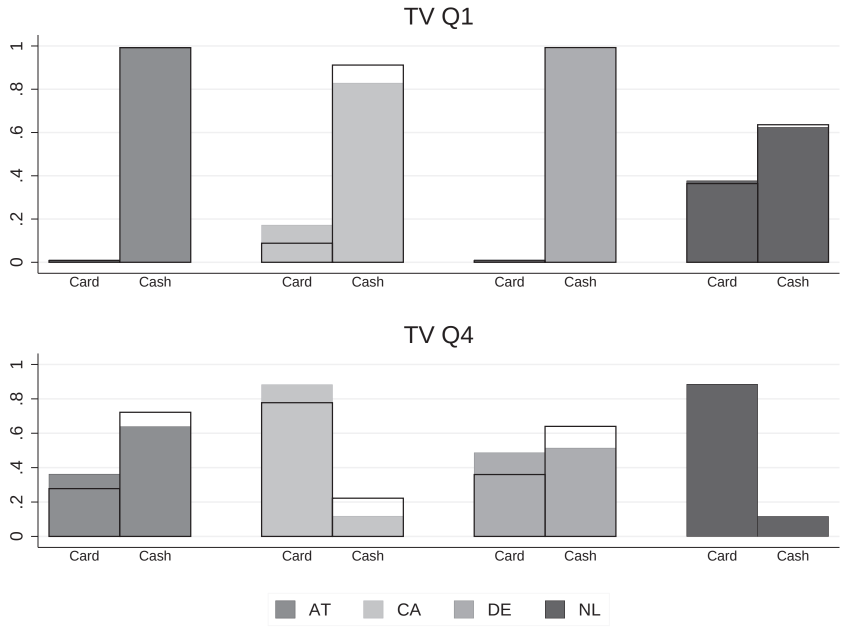
tried to alleviate this issue by using average cash balances of individuals and not cash balances before each transaction, we are aware that this does not completely solve the problem. For deeper analyses of this issue, we refer to Bouhdaoui and Bounie (2012), Arango et al. (2013), and Eschelbach and Schmidt (2013), who arrive at similar findings even when accounting for the possible endogeneity of cash balances.

Several results from our descriptive analysis indicate that card acceptance is likely to be important in consumers' choice between cash and non-cash. This result is reported in table 9, which shows that the rate of acceptance of cards at the POS has a significant negative effect on the probability of using cash (results are only available for AT, CA, DE, and, with limitations, NL). In order to understand the quantitative impact of this factor and to study how much it contributes to the level of cash usage across countries, we conduct a scenario analysis. In particular, we compare the baseline probabilities—i.e., the observed frequencies from the data—with the hypothetical values obtained by assigning each person the maximum group acceptance observed in the sample. Note that this does not necessarily mean that acceptance is raised to 1, because this would imply a far stretch from reality. Thus, the question we ask is by how much cash usage would decline if acceptance were as high as it is for the income/age group that reports the highest rate of acceptance.[31]

Figure 6 summarizes the results for the first and fourth transaction value (TV) quartile. For TV Q1, the effect on payment choice is trivial for AT, DE, and NL, while for CA it is significant. There is an almost 10-percentage-point increase in card usage for low-value transactions if payment cards were universally accepted. However, at TV Q4 the effect is similar across countries, as the probability of card payment increases relative to cash. This would imply that Canadians are more likely to pay with cards at all transactions if cards are universally accepted. High acceptance of cards will only increase card use for AT and DE when the transaction values are high. For NL, the effect would be minimal, which indicates that current levels

[31]This also implies that we do not expect country differences to vanish, as the maximum rate of acceptance can still differ across countries. All other variables are evaluated at their means.

Figure 6. Scenario Analysis: High Acceptance



Notes: The figure compares the unconditional predicted probabilities of cash use (transparent bars) with a scenario in which acceptance is set to the maximum observed group acceptance (and all other explanatory variables evaluated at the mean). The upper (lower) panel refers to transaction values in the first (fourth) quartile.

of acceptance are already relatively high at all transaction quartiles. These results highlight that country differences remain substantial.

6.2 Robustness Analyses

As one important robustness check, we focus on transactions completed at grocery stores and gas stations only. This exercise is inspired by the work of Klee (2008), who uses scanner data from grocery stores, and Cohen and Rysman (2013), who use scanner data from grocery stores and gas stations.[32] The results are reported in

[32]Klee (2008) focuses mainly on the value of time while controlling for census-tract averaged demographics. Her analysis does not have individual

table 10. Focusing on these sectors reduces the sample by about one-half to two-thirds. The results again confirm the roles of demographics and transaction value. These results are consistent with the findings of Klee (2008) and Cohen and Rysman (2013). In addition, we find that the results for the other variables do not change; we still find an independent effect for preferences, cash on hand, and payment location/type of product.

Finally, we perform a few additional robustness checks to ensure that difference in survey design does not drive the results. One, we estimate a logit using the transactions conducted on the first day of each diary to compare with the Dutch payment diary, which only collected data per respondent for one day. Two, we also generate estimates using only the first three days for AU, AT, DE, and FR that are comparable to those for CA and US. Neither of these modifications affects the main results. Three, we estimate the logit conditioning on the sample of respondents who owned a payment card (either debit or credit). The results for all sectors and the gas and groceries were quantitatively similar. These robustness checks are available in a supplementary appendix on the IJCB website (http://www.ijcb.org).

7. Reasons for Cross-Country Differences in Cash Usage

The estimation results provide a set of factors that are correlated with cash use. To understand why the cash share is higher in AT and DE compared with the other countries, we provide a brief discussion of the following six potential reasons for cross-country differences: (i) payment card acceptance at the POS, (ii) structure of purchases, (iii) shoe-leather costs and opportunity costs, (iv) financial and non-financial incentives, (v) behavioral aspects of payment choice, and (vi) the size of the shadow economy.[33]

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demographics, perceptions, or acceptance of cards. Cohen and Rysman (2013) analyze rich data on grocery purchases and are able to follow consumers over a longer time period. Their paper highlights the role of the transaction size.

[33] A deeper discussion of these factors is available in a supplementary appendix on the IJCB website (http://www.ijcb.org).

Table 10. Cash versus Non-Cash Payment Choice at Gas and Groceries (marginal effects)

	AU	AT	CA	FR	DE	NL	US
Medium Income	−0.025	−0.072*	0.042	−0.046**	−0.009	0.007	−0.133***
	(0.024)	(0.033)	(0.029)	(0.017)	(0.014)	(0.017)	(0.027)
High Income	−0.039	−0.08*	0.002	−0.073*	−0.012	−0.023	−0.162***
	(0.029)	(0.034)	(0.037)	(0.032)	(0.015)	(0.018)	(0.038)
Aged 36 to 59	0.086***	0.017	0.077**	0.056**	0.026	0.025	0.105***
	(0.023)	(0.026)	(0.024)	(0.017)	(0.014)	(0.017)	(0.032)
Aged Over 60	0.127***	0.04	0.08	0.042	0.069**	0.019	0.059
	(0.039)	(0.036)	(0.043)	(0.027)	(0.022)	(0.021)	(0.04)
Medium Education	−0.069*	0.056	−0.073	−0.053*	−0.043***	−0.005	−0.138*
	(0.028)	(0.045)	(0.051)	(0.023)	(0.013)	(0.016)	(0.061)
High Education	−0.102***	0.004	−0.123*	−0.106***	−0.118***	−0.03*	−0.21***
	(0.021)	(0.037)	(0.052)	(0.028)	(0.019)	(0.015)	(0.06)
Not Homeowner	0.035		0.046				0.053
	(0.02)		(0.029)				(0.029)

(continued)

Table 10. (Continued)

	AU	AT	CA	FR	DE	NL	US
Perceptions of:							
Ease	0.212***		0.161**				0.24***
	(0.055)		(0.055)				(0.048)
Cost	−0.077*		0.108				0
	(0.037)		(0.061)				(0.061)
Security	0.114***		−0.055*				0.045*
	(0.024)		(0.026)				(0.02)
Acceptance	−0.134*		−0.051				−0.008
	(0.056)		(0.076)				(0.057)
Card Acceptance Share at the POS	−0.178***		−0.561***		−0.08***	−0.565***	
	(0.032)		(0.036)		(0.018)	(0.04)	
Cash on Hand	0.003*	0.053**	0.006***	0.001***	0.003***	0.006***	0.002**
	(0.001)	(0.017)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
Gasoline	−0.088***	−0.071***	−0.011		−0.114***	−0.036	0.024
	(0.017)	(0.017)	(0.028)		(0.008)	(0.02)	(0.02)
TV Q2	−0.201***	−0.273***		−0.261***	−0.189***	−0.094***	−0.176***
	(0.029)	(0.025)		(0.036)	(0.028)	(0.018)	(0.027)
TV Q3	−0.302***	−0.409***		−0.495***	−0.34***	−0.207***	−0.336***
	(0.03)	(0.023)		(0.034)	(0.028)	(0.018)	(0.024)
TV Q4	−0.42***	−0.586***		−0.677***	−0.481***	−0.316***	−0.466***
	(0.029)	(0.021)		(0.029)	(0.027)	(0.021)	(0.024)
Observations	3,875	6,569	5,079	7,098	10,364	4,184	3,688

Notes: The dependent variable takes a value of 1 if a payment is made by cash and 0 if it is made by debit or credit. Results for location (urban/rural), marital status, gender, employment status, and family size are not shown. Variables are defined in table 13 in the appendix. TV Q2, TV Q3, and TV Q4 denote the second to fourth quartile of transaction values. We cluster standard errors at the person level. Standard errors are in parentheses and the 1, 5, and 10 percent levels of significance are denoted by ***, **, and *, respectively.

7.1 Card Acceptance at the POS

Tables 4 and 7 illustrate a correlation between card acceptance and cash usage. Table 7 shows that the share of purchases where cards are accepted is strictly smaller in DE and AT in comparison to CA; no such data are available for the other countries. This pattern can be observed for all transaction value ranges, but the difference is weaker for the transaction values above the median. This finding, which refers to survey respondents' subjective perceptions, is confirmed by the aggregate network data. The first column of table 11, showing the number of POS terminals per 1 million inhabitants, indicates that the POS density is by far the lowest in DE and AT. However, at the same time, we note that the POS density is not much higher in NL than it is in AT but there is a much lower cash share in NL. Yet, Huynh, Schmidt-Dengler, and Stix (2014) show that card acceptance exerts a strong impact on average cash balances, and table 4 confirms that cash balances are indeed higher in AT and DE. Further, Eschelbach and Schmidt (2013) utilize the German diary data to show that higher cash balances correlate with higher cash usage at the POS.

7.2 Structure of Purchases

The aggregate cash share for a given country could be influenced by the composition of expenditures, e.g., higher expenditure shares for food (FR) or for services (US). Additionally, the market structure of retailers could affect the cash share, e.g., if retailers are small or very large. While the effect of the latter channel is controlled for via card acceptance, the evidence we have presented in table 8 about the sectoral composition of expenditures does display some differences. We analyze the potential size of this compositional effect by computing a hypothetical cash share that assumes that all countries have the expenditure structure of Germany utilizing sectoral cash shares of table 8. These results suggest only minor differences—at most, 2 percentage points—in comparison to unadjusted cash shares. This suggests that the differences in cash usage are weakly correlated with differences in expenditure patterns.

Table 11. Number of ATMs and POS Terminals, Incidence of Robbery

	POS Density	ATM Density	Robberies
Australia	32,008	1,362	16.9
Austria	12,754	969	48.2
Canada	21,045	1,728	86.4
Germany	7,221	947	57.9
France	19,537	820	190.3
Netherlands	15,525	475	92.4
United States	17,019	1,385	112.6

Notes: Columns 1 and 2 show "Terminals located in the country: number of respective terminals per million inhabitants." Source: BIZ "CPSS Red Book statistical update" (Table 11b) and ECB Statistical Data Warehouse, values from 2011. Column 3 shows the number of robbery cases per 100,000 inhabitants. According to the United Nations Office on Drugs and Crime (UNODC) definition, "robbery" means the theft of property from a person, overcoming resistance by force or threat of force. Where possible, the category "Robbery" should include muggings (bag snatching) and theft with violence, but should exclude pickpocketing and extortion. Source: UNODC, values from 2011.

7.3 Shoe-Leather Costs and Opportunity Costs

Shoe-leather and opportunity costs, such as ATM density, risk of theft, and interest rate differentials, have been used to explain the difference in cash use. First, table 11 shows that the lowest ATM density is in FR and NL, which have a low share of cash usage and low cash balances. AT and DE are in the mid-range of observed values, while the highest ATM density is found in AU, CA, and US. This provides mixed evidence as to whether having high ATM density is negatively correlated with low cash share.

Second, table 11 summarizes the number of robberies per 100,000 inhabitants. Again the figures only provide partial support for the high cash share in AT and DE. These two countries have a lower crime rate than CA, US, FR, and NL. However, AU has the lowest robbery density. Hence, high cash balances and high cash use could be due to low crime rates in AT and DE.

Third, interest rate differentials are unlikely to explain much of the cross-country differences in cash use. Given the average size of cash balances, forgone interest income is small in absolute terms and cross-country interest differentials are small; see table 2 for a summary of interest rates.

7.4 Payment Steering through Financial and Non-financial Incentives

Table 12 summarizes the various financial and non-financial incentives for consumers to use payment methods. In CA and FR, the usage of surcharges is forbidden by the contractual rules of the payment schemes. In AU, AT, DE, NL, and in most US states, retailers are legally allowed to surcharge, but, as in CA and FR, the incidence of surcharging for POS payments is still rather low.[34] In all seven countries, retailers seem to sometimes provide discounts on cash payments, but for most consumer payments, cash discounts are not usual. Hence, the large cash usage in AT and DE does not seem to stem from differences in terms of surcharges and discounts applied by retailers.

Similarly, the larger use of cash in AT and DE does not seem to stem from differences in non-financial incentives used by merchants. In FR and NL, retailers have started various initiatives to stimulate card payments as opposed to cash payments, i.e., using stickers, special "card-only" registers, and explicitly asking consumers to pay by card. In the other five countries too, retailers use various methods to steer customers' payment behavior. However, in most cases, this involves steering consumers away from using high-cost payment cards to less expensive card alternatives, or from using cards for small transactions. Hence, there is no clear pattern of retailers steering clients away from cash in the countries where cash usage is significantly lower than in AT and DE.

The countries considered in this study differ in terms of initiatives taken by banks and card schemes to stimulate the use of payment cards. In AU, CA, FR, and US, consumers may receive rewards when using (particular) payment cards. However, in AT and DE,

[34]For instance, in AU, the incidence of surcharges being paid was estimated by a payment diary study conducted in November 2013 at around 4 percent of card transactions; see Ossolinski, Lam, and Emery (2014).

Table 12. Overview of Payment Market Structure

	AU	AT	CA	FR	DE	NL	US
Is surcharging allowed?	Yes	Yes	No	No	Yes	Yes	Yes
Do retailers surcharge particular methods?	Yes	No	Yes	No	Yes	Yes	Yes
Do retailers provide discounts of cash?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Do retailers use other, non-financial incentives to steer consumers (e.g., stickers, posters at the POS)?	Yes	No	Yes	Yes	Yes	Yes	Yes
Are retailers allowed to not accept particular cash denominations?	Yes	Yes	Yes	No	Yes	Yes	Yes
Have banks and other organizations launched initiatives to stimulate particular payment behavior (e.g., national campaigns)?	Yes	Yes	Yes	Yes	No	Yes	No
Were these initiatives taken by each organization jointly?	Yes	No	No	Yes	—	Yes	—
Do consumers get rewards for using cards?	Yes	No	Yes	Yes	Yes	No	Yes
Do consumers need to pay when withdrawing cash from an ATM of their own bank?	No	No	Yes	No	No	No	No
Do consumers need to pay when withdrawing cash from an ATM of another bank?	Yes	No	Yes	Yes	Yes	No	Yes

Notes: This table is collected from an informal survey of the co-authors from each respective country. For brevity, we denote the response with either Yes or No. However, there are some nuances to each of the questions, and a detailed table is available upon request.

card rewards are only minor. This may partly explain the relatively low card usage in AT and DE. In addition, in AU, CA, FR, and NL, nationwide campaigns have been used by card schemes, banks, and in some cases retail organizations, to promote the use and acceptance of payment cards and contactless payments among consumers and retailers. In AT, DE, and US, by contrast, promotional activities of banks and card schemes to stimulate (contactless) card usage are mainly limited to basic marketing activities. So, overall, the use of rewards and/or promotion campaigns for card payments in AU, CA, FR, NL, and US may have affected consumers' preferences and finally explain the relatively low usage of cash, as opposed to AT and DE, where both the use of rewards and promotion campaigns are limited.

Finally, differences in pricing of ATM withdrawals may affect consumers' payment choices. However, it is difficult to tell to what extent this may explain the differences across our seven countries. In AT, consumers can withdraw money at no cost at either an ATM of their own bank or another bank's ATM. However, the same is true in the NL. In all other countries, consumers may be faced with a fee, depending on the ATM they visit or the banking packages they have. Hence, there is no clear one-on-one relationship between ATM fees and cash usage.

7.5 Behavioral Aspects

There have been several behavioral explanations offered to explain payment choice. For example, von Kalckreuth, Schmidt, and Stix (2014b) show that cash is used by some consumers because it helps to monitor expenditures. However, Hernández, Jonker, and Kosse (2016) argue that cards may be used for the same purpose too. Budgeting features (e.g., frequency, actuality, and level of detail of account statements) of payment instruments may differ across countries. Therefore, someone who aims to keep track of their expenses could be a heavy cash user in DE, but in US or FR, for example, they could be a check user or a person who keeps a written record of their expenses.

The inter-war and post-World War II experience of very high inflation in AT and DE is sometimes cited as a reason for a preference for cash.[35] Although difficult to prove, we are skeptical about the relevance of this line of reasoning to explain payment behavior. First, one would suspect that the direct effect of previous high inflation history would be to use less (and not more) cash. Second, even if one recognizes that it is debt aversion that matters, according to which Germans and Austrians could use cash because they dislike debt, then one would presume that AT and DE use fewer credit cards and more debit cards (which is confirmed by our results), but not necessarily more cash. Third, in figure 3 we have documented that cash use by young AT and DE cohorts, which were not affected by any crisis, is also much higher than in the other countries.

A more relevant explanation for cash preference arises if a country has a history of banking crisis, which often coincides with high inflation and may affect trust in banks; see Stix (2013). However, this effect has been shown only for emerging economies, and we consider it unlikely that people in AT or DE trust their banks less than people from other developed countries. For AT, Knell and Stix (2015) show that trust in banks is very high. Moreover, evidence suggests that memories of a banking crisis fade after about twenty years; see Osili and Paulson (2014). Other behavioral aspects of payment behavior are similarly hard to investigate. Anonymity and security concerns are sometimes cited as influencing people's payment behavior. However, the level of anonymity and security people require when making payments is difficult to measure empirically.

7.6 Size of the Shadow Economy

The size of the shadow economy may have an impact on currency in circulation and hence on average cash balances. Therefore, it may also affect cash use for "official" transactions that are observed in diaries. In fact, a comparison of twenty-seven European Union countries reveals a strong negative correlation between the size of the shadow economy and the use of electronic payments; see figure 9 of AT Kearney (2013). Internationally comparable figures for the size of the gray economy are provided by Schneider and Buehn (2012)

[35] "Why Germans Pay Cash for Almost Everything," http://qz.com/262595/why-germans-pay-cash-for-almost-everything (accessed November 28, 2014).

and reveal that US has the lowest gray economy share with 9.1 percent of official GDP, and CA, FR, and DE have the highest share, with about 15 percent. AT has the second lowest share (11 percent). In other words, we find little evidence for a correlation between the size of the shadow economy and the use of cash for payments in our sample countries.

8. Conclusions

Many have predicted and espoused the view that cash is increasingly disappearing as a payment instrument; see Wolman (2012). However, to paraphrase Mark Twain, we would say that the *reports of the death of cash have been greatly exaggerated.* This paper shows that in all seven countries considered, cash is still used extensively—particularly for low-value transactions. In some European countries such as Austria and Germany, cash even dominates consumer payment choices for all transaction values.

This paper demonstrates that, apart from transaction sizes and consumer preferences for ease of use, the use of cash is strongly correlated with demographics and POS characteristics such as merchant card acceptance and venue. This largely confirms the results of earlier studies that were based on data from only one or a small number of countries. Our finding that these results can be observed for all seven countries assures us that these are universal factors driving cash use.

Our paper signals the importance of cross-country differences. First, the level of cash usage differs across the various countries. Second, differences can be found in the type of alternatives used for cash. Some countries often use credit cards as a substitute; in other countries, mainly debit cards are used. One explanation for these cross-country differences could be found in differences in card acceptance and the pricing and stimulation policies of retail payments banks, payment schemes, and retailers. Rysman (2009), for instance, highlights how market structure affects payments, or vice versa. Third, we point to an important correlation between cash use and the amount of cash balances consumers carry. The direction of the correlation remains unclear.

This paper has provided a comprehensive harmonization of payment diaries so as to understand cross-country differences. We have highlighted substantial cross-country differences that remain unexplained, and, given the remaining questions on the role and effect of cash balances, further work is required to more fully ascertain the underlying drivers of consumers' use of cash and alternative payment methods. Further, we provide a comprehensive review of work completed and outline possibilities for future research.[36]

Appendix

Table 13. Definition of Payment Variables

Income	Three dummy variables; 1 if income is in the highest income tercile (High Income), lowest income tercile (Low Income), or the middle income tercile (Medium Income), and 0 otherwise.
Age	Three dummy variables; 1 if age of respondents is above 60 (Aged over 60), between 36 and 59 (Aged 36 to 59), or between 18 and 35 (Aged under 36), and 0 otherwise.
Education	Three dummy variables: low education, middle education, and high education. Although the exact definitions depend on the country, the definitions are based on whether a respondent has finished mandatory schooling, secondary schooling, and some post-secondary education.
Not Homeowner	Dummy variable; 1 if respondent does not own his place of residence.
Perceptions	The analysis employs perceptions on ease of use, cost, security, and acceptance. These are derived from the question as to how much cash fulfills the listed attributes. The values are

(*continued*)

[36]The supplementary appendix on the IJCB website contains a discussion of the current research conducted and an overview of new potential research avenues using payment diaries.

Table 13. (Continued)

	normalized by results for other methods of payment, such that a positive (negative) value implies that cash is valued better (worse) than case or credit. The normalization is described in Arango, Huynh, and Sabetti (2015).
Cash on Hand	Defined as the usual (average) cash holdings of a person. Values for AU and NL are from the questionnaire ("typical" average cash balance); all other values are from the diary. We drop all observations above the 99.5 percent mark and normalize this variable. As a consequence, "Cash on Hand" is a unitless scalar.
Type of Purchase	Several dummy variables; 1 if purchase is classified as grocery, gas station, semi-durable, services, or entertainment, and 0 otherwise.
Transaction Value Quartiles	Quartiles are formed from all observed transaction values. Four dummy variables, which are 1 if a transaction falls in trasaction value quartile 1 to 4 (TV Q1 to TV Q4), and 0 otherwise.
Card Acceptance Share	Respondents indicate whether a transaction could have been conducted by card. From these observations, we calculate the share of transactions with card acceptance for each individual. To avoid endogeneity, we then calculate the mean of individual card acceptance shares for nine pre-specified population groups that are formed from three income and three age groups. "Acceptance Group" thus reflects the mean acceptance of the income/education population group that a respondent belongs to.

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Death of a Reserve Currency*

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The Dutch bank florin was the dominant currency in Europe over much of the seventeenth and eighteenth centuries. The florin, a fiat money, was managed by an early central bank, the Bank of Amsterdam. We analyze the florin's loss of "reserve currency" status over the period 1781–92, using a new reconstruction of the Bank's balance sheet. The reconstruction shows that by 1784, accommodative policies rendered the Bank policy insolvent, meaning that its net worth would have been negative under continuation of its policy objectives. Policy insolvency coincided with the Bank's loss of control over the value of its money.

JEL Codes: E58, F33, N13.

1. Introduction

The U.S. dollar reigns as the dominant reserve currency today. The British pound occupied a similar status in the nineteenth and early twentieth centuries. Preceding the British pound in this leading role

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was the Dutch guilder, also known as the florin. This paper explores the florin's loss of reserve currency status over the period 1781–92, employing a new data set assembled from archival sources.

This historical episode is of continued relevance because the reserve-currency florin was in many ways a modern construct. The "florin" in question was not a coin. It existed only as ledger entries in the accounts of an early central bank, the Bank of Amsterdam (or "Bank"). And, unusually for the time, the Bank's money was not inherently redeemable in coin, nor was its value defined by any specific coin. To call it by its modern name, the florin was fiat money.

As a supplier of fiat money, the Bank of Amsterdam engaged in many of the same activities as central banks today. The Bank operated a large-value payment system; it provided liquidity to the Amsterdam money market through repo-like arrangements; it engaged in open-market operations to stabilize market conditions; it lent to selected counterparties; and it returned seigniorage to its sponsoring government, the City of Amsterdam ("City"). The main policy objective of the Bank was to stabilize the market price of its money relative to high-quality collateral—the large-denomination "trade coins" circulating among merchants in Amsterdam—while smoothing short-term fluctuations in the stock of Bank money. The Bank's adherence to this goal of "price stability" made the florin into a bellwether money for much of the seventeenth and eighteenth centuries.

When confronted with a major crisis in 1781, the Bank reacted in a manner that may also seem familiar to modern observers. Responding to the outbreak of war between the Dutch Republic and Britain (the Fourth Anglo-Dutch War), the Bank embarked on a policy of aggressive open-market purchases. This policy was paired with an unprecedented increase in the Bank's lending activity to a large government-sponsored enterprise called the Dutch East India Company ("Company"). This last policy was especially daring, as wartime disruptions to the Company's operations soon meant that it was in no position to repay its debts. By 1783, the value of the florin began to suffer. The Bank then reacted by reversing the direction of its open-market activity, but it lacked adequate reserves with which to conduct defensive operations.

The Bank's difficulties soon ran deeper than illiquidity, however. Our data show that by 1784, non-performance of the Bank's credit portfolio had caused it to become "policy insolvent," meaning that its net worth was negative under its policy objectives (Stella and Lönnberg 2008). A lasting solution to the Bank's problems required either a fiscal intervention or a policy shift, but neither option was pursued at this stage.

Pressure on the bank florin grew acute in 1790, following the outbreak of the French Revolution. The Bank responded by attempting to enforce a sudden 9 percent reduction in the value of its money relative to silver. Protests from market participants led the City to instead inject capital into the Bank over 1791–92. The recapitalization temporarily halted the decline in the value of the florin, but it was unable to restore the Bank's credibility over the longer term. The reconstructed data show that the capital injection failed to remedy the Bank's policy insolvency, in large part because the City did not give up its claim on the Bank's future income. The data also reveal that much of the injection was immediately diverted back to the City's own fiscal needs.

The end of a currency's reserve status is a rare event, and the florin's downfall teaches that preeminence of a central bank does not necessarily guard against fiscal over-exploitation or a sudden loss of market confidence. Our reconstruction offers a precise narrative of a dominant currency's quick transition from a reserve asset to a monetary also-ran. The transition is punctuated by two large monetary shocks—the wartime crises of 1781 and 1790—and two mismanaged policy responses. The first response—the expansionary bravado of 1781–83—undermined market confidence in the Bank. The second—the belated and ineffective recapitalization of 1791–92—helped ensure that this loss of confidence would be permanent.

The rest of this paper is organized as follows. Section 2 reviews some relevant literature. Section 3 lays out the structure and policies of the Bank. Section 4 provides a detailed analysis of the florin's collapse. A concluding section considers the implications of this episode for modern central banking practice.

2. Connections to the Literature

The narrative history of the Bank of Amsterdam's decline is known from the classic works of Mees (1838) and van Dillen (1925, 1964). Van Dillen (1934) provides an English synopsis of this history and year-end summaries of the Bank's accounts. Our analysis extends this literature by providing the first detailed, high-frequency (monthly) breakdown of the Bank's balance sheet over this period (1775–92), presented in a manner compatible with modern central bank accounting. Examination of the details provides new insights, e.g., the course of the Bank's open-market operations, the extent of its insolvency, and the failure of the City's attempted recapitalization.

A precise reconstruction is possible because virtually complete records of the Bank have been preserved for this sample. Certain income items are only recorded annually; otherwise the quality of the accounting information approximates that of a present-day central bank. In earlier periods of the Bank's existence (see Quinn and Roberds 2014b for 1666–1711), records concerning asset holdings are very incomplete, so the composition of the Bank's assets has to be guessed at from changes in the Bank's liabilities (i.e., ledgers).

Central bank accounting and central bank solvency in particular are studied in a large body of literature, recently surveyed in Archer and Moser-Boehm (2013). A prominent theme of this literature is that standard concepts of solvency are difficult to apply to central banks, which, because of the unique monetary status of their liabilities, are often able to operate with thin or even negative levels of equity (assets minus liabilities). Below we will show that the Bank of Amsterdam offered no exception to this rule, as its equity was virtually always negative. Fry (1993) argues that net worth (equity adjusted for "off-balance-sheet" items including discounted future seigniorage income[1]) provides a better measure of the sustainability of a central bank's policies than does conventional equity.[2] Intuitively, a central bank with positive net worth can meet its financial commitments by issuing debt claims against future income. Negative net worth is problematic, since it indicates a central bank may be forced to compromise its policy goals in order to meet expenses.

Fry's conclusions have been echoed in subsequent papers, theoretical and empirical (see, e.g., Stella 1997, 2005; Ize 2005; Buiter

[1]Archer and Moser-Boehm (2013, p. 7) call this "comprehensive net worth."

[2]The empirical relevance of this distinction is easily seen from figures compiled by Archer and Moser-Boehm (2013, p. 11) for the European Central Bank (€411 billion equity versus €5.1 trillion estimated net worth in 2010) and the Federal Reserve System ($134 billion equity versus $4.1 trillion estimated net worth in 2010).

2008; Klüh and Stella 2008). Our data set will offer some additional confirmation. Del Negro and Sims (2014) emphasize, however, that estimates of a central bank's net worth can vary widely with projections of money demand and with expectations of policy. This is an issue that is present in our calculations, as will be seen below.

A related theme of this literature is the importance of fiscal backing for the effectiveness of central banks, and particularly of mechanisms for recapitalization under certain scenarios. Sims (2004) lays out the essential policy dilemma, arguing that a central bank without credible fiscal backup will either miss its policy targets or be forced to amass politically unsustainable amounts of reserves (to fend off speculative attacks). Below we describe how the Bank of Amsterdam traditionally confronted this dilemma by using market funding. Its continuous rollover of market-supplied reserves both anchored policy targets and prevented the City from depleting this category of reserves. Confidence in this solution met its limits in 1781–83 when the Bank was called upon to provide emergency funding to the cash-strapped Dutch East India Company. The inadequate recapitalization of 1791–92 made the Bank's lack of fiscal underpinnings all the more evident to contemporary observers.

Recently there has been an upsurge of interest in the topic of central bank accounting, stemming from the rapid expansion of central banks' balance sheets since the 2008 crisis (see Fawley and Neely 2013 for a survey). A number of studies (as of this writing, Stella 2009; Christensen, Lopez, and Rudebusch 2013; Greenlaw et al. 2013; Hall and Reis 2013; Del Negro and Sims 2014; Carpenter et al. 2015) have considered the effects of the Federal Reserve's quantitative easing (QE) programs on its equity position going forward.[3] One message of this literature is that the unwinding of QE could diminish the Federal Reserve's equity by as much as $100 billion under unfavorable scenarios, although book equity must remain non-negative under the Federal Reserve's accounting rules.[4] Even potential losses of this magnitude, however, are dominated by other components of the Federal Reserve's net worth, estimated in trillions

[3]Comparable exercises for the European Central Bank can be found in Buiter and Rahbari (2012) and Hall and Reis (2013).

[4]If the Federal Reserve's income were to be insufficient to cover expenses, its accounting rules call for the creation of reserves against a "deferred asset," which is a claim against future remittances by the Federal Reserve to the U.S. Treasury.

of dollars when potential income from note seigniorage is included in the calculation (Buiter and Rahbari 2012; Del Negro and Sims 2014). Equity impacts from the unwinding of QE are thus seen as unlikely to constrain the Federal Reserve's future policy decisions.

The discussion below will make clear that while the design of the Bank of Amsterdam was in many respects comparable to modern central banks (including the Federal Reserve), one major difference was that it did not issue circulating notes backed by a transparently funded government debt. In the eighteenth century this was a new concept of central banking, one that was still being worked out by the Bank of England (Clapham 1970a) and other institutions. The corresponding lack of access to a stable stream of earnings had negative implications for the Bank of Amsterdam's financial stability. As will be seen below, the Bank did have other sources of income, which, though adequate in normal times, proved insufficient during the circumstances of 1781–92.

The demise of the Bank of Amsterdam ushered in a long period of currency dominance for the British pound. The passing of the torch from the florin to the pound in the 1780s has a number of parallels with the better-known transition from the pound to the dollar in the 1920s and 1930s (Eichengreen and Flandreau 2009, 2010). These include the pound's loss of trade dominance to the dollar in the early twentieth century, the initial weakening of the pound by the fiscal pressures of World War I, followed by a second crisis and the removal of the pound from the gold standard in 1931 (Kindleberger 1984). There are also some significant differences. Chief among these is that the pound survived (though in a diminished role) while the bank florin did not. France's military conquest of the Dutch Republic in 1795 brought about the last phase of the florin's collapse. After the Napoleonic period, the remnant portion of the Bank of Amsterdam was liquidated, and its functions were taken over by a national institution of the newly established Kingdom of the Netherlands, De Nederlandsche Bank (Jonker 1996).

3. Some (Very) Old-Style Central Banking

This section describes the Bank of Amsterdam's structure and balance sheet. Additional details are provided in van Dillen (1934), Dehing (2012), and Quinn and Roberds (2014b).

Table 1. Balance Sheet of the Bank of Amsterdam (Eighteenth Century)

Assets	Liabilities
Coins under Receipt (Those Eligible for Repurchase) Unencumbered Coins (Not Eligible for Repurchase) Loans	Account Balances Equity

The Bank was founded in 1609 and liquidated in 1820. It was owned by the City of Amsterdam and was directed by an appointed commission of merchants, bankers, and former municipal magistrates ('t Hart 2009, p. 154). The principal objective of the Bank was to provide a stable money for the settlement of bills of exchange payable in Amsterdam. As noted above, this involved stabilizing the value of the bank florin relative to trade coins. This stability made payment by book-entry transfer of Bank balances popular with the international bill market, and use of Bank money generated revenue for the City.

3.1 Balance Sheet Structure

Table 1 gives a stylized balance sheet for the Bank of Amsterdam during our era of interest.

Table 1 reveals two fundamental differences between the Bank and modern central banks. The first is on the asset side, where the traditional "building blocks" of the Bank's portfolio were not government securities but silver (much less often, gold) coins.[5] The

[5]There were several reasons why the Bank used coins rather than government bonds as its principal backing asset. Public finance in the Dutch Republic was relatively advanced for its era, but unlike contemporary Britain, there was no unified national debt (de Vries and van der Woude 1997, chapter 4). The debt of the largest province, Holland, played a somewhat similar role to a national debt (Gelderblom and Jonker 2011), but secondary markets for Holland debt were generally quite thin (van Bochove 2013). Finally, the charter of the Bank did not incorporate any explicit role for the Bank in public finance. The coins held by the Bank may be compared to foreign exchange assets held by many modern central banks; see the discussion below.

second is on the liability side, where the Bank's monetary liabilities existed only as balances on its books, never as circulating notes.[6]

Assets in modern central banks' portfolios are often held under repurchase agreements. The Bank did not engage in repurchase agreements, but it did create money through a comparable mechanism, famously described by Adam Smith in *The Wealth of Nations* (1937, pp. 446–55). Anyone with an account at the Bank could sell high-quality, large-denomination coin (known as "trade coin"[7]) to the Bank at a fixed price, receiving in return a credit in their account with the Bank, and a *receipt.* The receipt entitled its holder to repurchase the same coin within a six-month interval at the same price they sold it for, plus a small fee (1/4 percent for most silver coins and 1/2 percent for gold coins).[8] Receipts were issued in the name of the party selling the coin, but were fully negotiable.[9] Receipts could also be rolled over at six-month intervals, at the same cost as a redemption. In practice, most receipts were eventually redeemed, so they functioned much like "term repos" between the Bank and its account holders. Table 2 gives an example of how this type of transaction is recorded.

In the table 2 example, the Bank's records show that the firm of Elmenhorst & Kerkoff delivered 2,000 silver *driegulden* coins to the

[6]This mattered because it meant that the Bank's money was a "wholesale" product used primarily by wealthy merchants. During our era of interest, there were approximately 2,000 accounts at the Bank, held by about 1 percent of Amsterdam's population (van Dillen 1925, p. 985). The average value of a payment over the Bank's books was 2,500 florins (Dehing 2012, pp. 82, 140); a typical laborer's daily wage was about 1 florin (de Vries and van der Woude 1997, p. 616). Payments through the Bank thus resemble payments over today's large-value settlement systems (Fedwire, TARGET2, etc.).

[7]Trade coins had special liquidity value as the preferred medium of exchange for transactions in foreign markets. Both foreign and domestic trade coins were eligible for sale against receipts at the Bank.

[8]That is, in modern terms, a receipt was an American call option on the coin sold, the strike price being the original sale price plus the fee. A receipt was also a put option on the bank florin. Coins under receipt were tested for quality and held in standardized, numbered bags. In the original implementation of this system, someone redeeming a receipt received literally the same bag of coins that were sold to generate the receipt. Later on, the Bank appears to have allowed some substitution of fungible bags across receipts.

[9]Unfortunately very few prices of receipts have survived, so these cannot be employed in the analysis below.

Table 2. Receipt Transactions on the Balance Sheet, in Bank Florins

Assets		Liabilities and Equity	
July 26, 1776			
Coins under Receipt	+5,650	+5,650.0	Accounts
January 31, 1777			
		−14.1	Accounts
		+14.1	Equity
July 3, 1777			
Coins under Receipt	−5,650	−5,650.0 −14.1 +14.1	Accounts Accounts Equity
	0	0	Net Change
Source: Amsterdam Municipal Archives.			

Bank in the summer of 1776. The Bank credited the firm 5,650 bank florins and gave them a receipt. Six months later, the firm paid 25 basis points (= 14.1 florins) to the Bank (from other funds it had on account) to extend the receipt for another half-year. Then, in the summer of 1777, the firm used the receipt to repurchase the coins, paying another 25-basis-point fee (again from other funds). The last line of the table gives the cumulative net impact over all balances recorded in the ledgers, including the balance in the Bank's own master account.

A curious quality of the Bank's liabilities (i.e., account balances), of great fascination to Adam Smith and other contemporary observers, was their fiat nature (Smith 1937, p. 450). After the introduction of the receipt system in 1683, Bank balances *could no longer be redeemed for coin without a receipt.* This led to the creation of a daily secondary market in Bank funds, in which Bank money could be traded against (the equivalent of) circulating coin or "current money." Bank money, which was backed predominantly by trade coins, almost always went at a premium (called the *agio*) to current money, which consisted of a mixture of coins of varying quality. The distinction between Bank money and current money gave rise to two legally distinct, parallel units of account in the Dutch Republic, known as the *bank florin* or bank guilder, and the *current florin* or current guilder. For expositional shorthand, we will often use the term "florins" for bank florins and "guilders" for current florins.

In the table 2 example, each coin brought to the Bank had an official value of 3 current guilders and also an official value of 2.825 bank florins, so, for these transactions, the Bank used an (implicit) exchange rate of 1.062 guilders per florin. The secondary market, however, typically offered an exchange rate of 1.05 or less.[10] If instead Elmenhorst & Kerkoff had sold its coins to a private broker or "cashier" for bank florins at an agio of 5 percent, then the firm would have gained an extra 64 bank florins but no receipt. Most people chose the extra money, and the receipt business in *driegulden* coins was thin. Indeed, we use that coin in table 2 precisely because its infrequency allows us to connect individual transactions. In contrast, another Dutch silver coin, the *ducaton*, had a bank exchange rate of 1.05 and a substantial receipt business.

In addition to coins held under receipt arrangements, the Bank held coins not encumbered by receipts. These might consist of coins for which receipts had expired, but more commonly these were coins acquired through the Bank's open-market operations, i.e., through purchase of coin in the daily market for Bank funds. In the eighteenth century, such operations were generally conducted in small-denomination coins (*gulden* coins with a nominal value of one current guilder each). These coins were not recognized as trade coins and were thus ineligible for sale to the Bank against receipts. To ease monetary conditions, the Bank would on occasion purchase such coins (by crediting the seller's account with Bank funds, much as central banks today) at the going price (always less than one bank florin per guilder for a positive agio). Such open-market purchases

[10] That is, in modern terminology, the Bank often applied a small haircut to the coins purchased at its receipt window. The size of the haircut was determined by the difference between the market and official values of the coins bought. In the table 2 example, the implied haircut would have been $100 \times [(1/1.05) - (1/1.062)] = 1.08$ percent.

Table 3. Open-Market Operations on the Balance Sheet, in Bank Florins

Assets		**Liabilities and Equity**	
January 30, 1778			
Unencumbered Coins	+39,952.38	+40,000.00 –47.62	Accounts Equity
February 11, 1778			
Unencumbered Coins	–39,857.14	–40,000.00 +142.86	Accounts Equity
	+95.24	+95.24	Net Change
Source: Amsterdam Municipal Archives.			

expanded the stock of Bank funds, in the same way that central bank open-market purchases do today. To tighten, the Bank would sell guilder coins into the market.[11]

An example may be instructive. At the start of 1778, the Bank purchased 42,000 *gulden* coins at a premium or agio of $4\frac{7}{8}$. The next month, the Bank sold the same coins at $4\frac{5}{8}$. Table 3 gives the balance sheet effects. Note that, by convention, the Bank always recorded coin purchases and sales in its account balances "as if" these transactions occurred at a 5 percent premium (i.e., at 40,000 florins in this case). Each operation therefore requires a profit or loss adjustment to correct for the difference between actual transaction price and the benchmark 5 percent price of Bank money (for details see Quinn and Roberds 2014a).[12]

[11] Guilder coins were purchased with bank florins at a market price, rather than a fixed price as with trade coins. Also, no receipts were given for purchased guilders, so that someone who sold their guilders to the Bank had no right to withdraw coin from the Bank without the purchase of a receipt from someone who had sold trade coins to the Bank. This is somewhat analogous to the situation with modern central banks, where a party that sells collateral to a central bank in a repo may (and is expected to) later repurchase that same collateral at a fixed price, but a party that sells a security outright to a central bank may not then expect a return of that security at a prearranged price.

[12] We suspect this accounting convention was adopted to simplify bookkeeping. For lack of practical alternatives, our reconstruction reluctantly follows this

The unencumbered coin residing in the Bank's vault was a source of revenue for the City. Annually, the City paid itself a seigniorage "dividend" by removing the Bank's profit from the previous year, so the Bank had no retained earnings. Occasionally, the City would take more coin and call it a loan to prevent the Bank from having to acknowledge its negative equity position. The City paid neither interest nor principal to the Bank. Throughout this paper, we treat City "loans" as takings and adjust the Bank's equity accordingly.

The charter of the Bank prohibited lending activity. In practice, however, the Bank routinely lent to the Dutch East India Company. For most of the eighteenth century, Bank lending to the Company took the form of short-term loans that allowed one year's trading fleet to be dispatched while the previous year's fleet was still on its return voyage from Asia. These loans provided a regular source of income to the Bank (Uittenbogaard 2009). Occasional loans to the Province of Holland added a minor source of income.

To give an example of this type of transaction, in April 1775, the Company borrowed 100,000 unencumbered florins from the Bank at 3 percent.[13] Eighteen days later, the loan was repaid with interest. Table 4 gives the balance sheet effects (in this example, the Company has sufficient funds available to repay the interest and principal on the loan).

Putting the elements together, the Bank of Amsterdam was an amalgam of two structures. The receipt system created a "narrow bank" with 100 percent reserves that could be withdrawn on demand. This portion of the bank generated fee income. At the same time, a fractional reserve bank made loans backed by unencumbered coins. This portion generated interest income and profits from open-market operations. Reflecting this dual structure, we find it convenient to divide Bank balances into those matched by an unexpired coin receipt ("encumbered balances") and other balances ("unencumbered balances"). It should be emphasized, however, that this is

convention. For much of our sample, this results in some undervaluation (on the order of 1/2 percent) of the Bank's total assets relative to market value. This distortion is, however, swamped by fluctuations in the value of the Bank's credit portfolio.

[13]That is, the Company received the loan as balances in its Bank account. This was the usual type of loan, although on rare occasions, the Company would also borrow coin from the Bank.

Table 4. East India Company Borrowing on the Balance Sheet, in Bank Florins

Assets		Liabilities and Equity	
April 6, 1775			
Loans	+100,000	+100,000	Accounts
April 24, 1775			
Loans	–100,000	–100,000 –150 +150	Accounts Accounts Equity
	0	0	Net Change

Source: Amsterdam Municipal Archives.

an artificial distinction that never occurs in the Bank's accounts: the right to redeem Bank balances in coin was bound to receipts rather than the balances themselves.[14]

3.2 Monetary Policy

As a central bank in an open economy, the Bank of Amsterdam was subject to the constraints of the standard policy trilemma—mutual incompatibility of fixed exchange rates, absence of capital controls, and control over the money stock. The Bank generally attempted to resolve the trilemma by ceding control over its money, with some qualifications. By offering to "repo" trade coins, the Bank anchored (within arbitrage bands) the value of its balances vis-à-vis silver, which served as the metallic standard for most of eighteenth-century Europe. There were no capital controls, and apart from occasional

[14] This dual structure invites comparison to the Bank of England following the passage of Peel's Act in 1844. This law split the Bank of England into Banking and Issue departments, constrained the size of the former, and enforced a 100 percent marginal backing requirement on the latter (Clapham 1970b). Bank florins matched with a receipt similarly had 100 percent backing. However, all Bank of England liabilities (notes and accounts) retained an inherent right of redemption whereas Bank of Amsterdam accounts did not.

open-market interventions, the stock of Bank money ebbed and flowed according to market conditions.

In very approximate terms, the operation of the Bank's receipt window may be compared to a modern "corridor" or "channel" system for the implementation of monetary policy (e.g., Keister, Martin, and McAndrews 2008). In Amsterdam, the corridor's "ceiling" or lending interest rate was given by the 1/4 percent six-month redemption fee for receipts, or slightly more than 1/2 percent annualized. The Bank could afford to offer credit on such generous terms since, by structuring redemption of a receipt as an optional repurchase (rather than a loan repayment), the Bank had an airtight claim on the coin collateral, comparable to that of a funds seller in a modern repo transaction (see, e.g., Gorton and Metrick 2010). The "floor" or deposit rate for the policy corridor was always zero, since the Bank levied no charges for simply holding money in an account, nor did it pay interest to account holders.

Unlike modern central banks, the Bank had no mechanism for shifting this corridor as a way of tightening or loosening policy. Also, credit extended by private lenders would have been at interest rates above the corridor; the historical literature (e.g., Mees 1838, pp. 136–40) indicates that the receipt contract was a special type of credit arrangement only available through the Bank. Secured loans against various types of collateral were common, but since private lenders' claims on collateral were subject to bankruptcy stay and thus to liquidity risk (e.g., de Jong-Keesing 1939, pp. 124–5), higher haircuts and higher interest rates resulted.[15] Nonetheless the ready availability of funds through the Bank's receipt window exerted downward pressure on the cost of credit in Amsterdam's money markets.

The general design of the Bank is reminiscent of a modern currency board, but again there are some notable differences. First, the Bank did not offer to buy and sell foreign exchange at fixed prices, but instead offered fixed terms for the equivalent of repo transactions in trade coins, both foreign and domestic. Second, the Bank's operational target was not a foreign exchange rate, but rather the market value of the bank florin's domestic exchange expressed through the

[15]Private-sector repos of East India Company stock were common from the mid-seventeenth century (Petram 2011; Koudijs and Voth 2014). The market risk of such transactions meant that a haircut of about 20 percent was applied.

agio. Throughout most of the eighteenth century, the agio remained within the $4^1/2$ to 5 percent range that was embodied in the coinage laws of the Dutch Republic. These assigned two official values to each trade coin, one in bank florins and a slightly higher one in current guilders (Polak 1998, pp. 73–74). An agio within this range signaled a stable value of the bank florin relative to circulating money. Third, maintenance of the agio appears to have been a largely informal objective, as an explicit target band is not mentioned in the Bank archives until 1782 (van Dillen 1925, pp. 433–4). Informality of its target band allowed the Bank to engage in operations to smooth short-term fluctuations in its money (Quinn and Roberds 2014b). The Bank was also sometimes willing to tolerate deviations of the agio from its target range during periods such as the Seven Years' War (1754–63), when heavy wartime demand for coin depressed the agio to around 2 percent.

A fourth and final difference between the Bank and modern currency boards is that the latter typically operate with a 100 percent (or greater) "backing ratio" of external assets to central bank money. The Bank, on the other hand, often operated with a backing ratio that was substantially lower, averaging 80 percent over its lifetime (Dehing and 't Hart 1997, p. 49). One reason the Bank may have felt comfortable with this lower ratio was the relatively lax, informal nature of its policy target. Another reason may have been the apparent safety of the receipt system: account holders could not threaten the Bank with a classic bank run, since the Bank did not traditionally redeem its balances except against a receipt, and the total stock of receipts was always less than the stock of bank florins. The market value of the bank florin could suffer, however, and for the Bank, the safety of the receipt system ultimately proved more apparent than real.

3.3 Reserve Currency Role

Modern-day reserve currencies serve as backing assets for other currencies. In the eighteenth century, it would have been impossible for any bank liability to play this role, for two reasons. In the case of Amsterdam, one reason was operational: the City limited ownership of Bank accounts to local residents (in practice, merchants and wealthy individuals), its own treasury, and government-sponsored entities such as the Dutch East India Company. The other was conceptual: in the eighteenth century, the only universally acceptable backing asset for money was precious metal.

Even so, Amsterdam's combination of steady exchange rates, absence of capital controls, and low interest rates conferred something of a "reserve currency" status on the bank florin, in the sense of a "vehicle currency" or preferred medium of exchange (Devereux and Shi 2013). For example, it was fairly commonplace for, say, a merchant in, say, London to pay for goods imported from, say, Gdansk with a bill drawn on Amsterdam.[16] Bills drawn on Amsterdam and payable through the Bank were a liquid form of short-term credit readily available in most European commercial cities (Flandreau et al. 2009, Dehing 2012). The bank florin was a "reference" unit of account for commercial transactions over much of Europe (Gillard 2004 calls it "the European florin"), and top-quality bills on Amsterdam were a reliable and liquid store of value.[17] At the center of this network, in Amsterdam's capital markets, the bank florin served both as numeraire and the most liquid medium of exchange. The Bank was seen as a bulwark of financial stability and attracted favorable reviews from observers such as Adam Smith, William Paterson (who proposed the design of the Bank of England), and Alexander Hamilton (Smith 1937, p. 451; Paterson 1694, p. 14; and Hamilton 1851, p. 164).

By 1770 or so, however, Europe's financial center of gravity was clearly shifting toward London (Carlos and Neal 2011). Amsterdam's markets nonetheless continued to thrive during the 1770s. Quantitative indicators such as the level of Bank balances and payments activity show relatively modest declines from peak values observed in the 1760s (Dehing 2012, p. 82).

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[16]Available payment statistics support the claim that the florin served as a vehicle currency. The annual value of payments made through the Bank peaked in the 1760s at about 1.5 times the Dutch Republic's annual GDP. For a pre-industrial economy this seems a respectable level of activity; similar ratios for the United Kingdom in 1868 and the United States in 1955 are 3.6 and 2.7, respectively (Kahn, Quinn, and Roberts 2014).

[17]Bills of exchange drawn on merchant banks served this role rather than deposit accounts in banks or government securities. Deposit banking existed in eighteenth-century Amsterdam but was underdeveloped relative to contemporary Britain (Jonker 1996, pp. 233–6). By contrast, bills on reputable merchant banks were widely available and easily traded in secondary markets.

3.4 Equity, Income, and Net Worth

As explained above, the Bank did not hold a portfolio of government securities, nor did it issue circulating notes. This meant that the Bank did not have access to the most common source of revenue for modern central banks, which is seigniorage income from notes backed by government bonds. The Bank did have other streams of income, however, and it was solidly profitable for most of its existence. This section presents a summary of the Bank's income and expenses, and describes how these impacted the evolution of its net worth. Full details are given in Quinn and Roberds (2014a).

In basic terms, the Bank's equity at time t is the value of its stock of unencumbered coin plus its loan portfolio, minus its "unencumbered accounts" (those accounts not matched by receipts). The Bank's time-t net income (or profit) is given by the sum of income from loans, losses on purchases (gains on sales) of coin, fee income from receipts, and other fee income; less loan write-offs, operating expenses, and profit taking by the City.[18]

Following the literature reviewed in section 1, the *net worth* of the Bank is given by the value that a hypothetical, fully informed outside investor would place on the Bank. Operationally, net worth is derived by adjusting book equity for off-balance-sheet income and expenses. For the Bank of Amsterdam, expected profits from fees, expected interest on certain short-term credits,[19] and expected operating expenses are off balance sheet until realization. In contrast, the expected income from annuity-style debts is on balance sheet because the future value of the income streams are embedded within asset values on the balance sheet. Our estimates of net off-balance-sheet incomes assume (i) that such profits follow a random walk, and (ii) that going forward, the City does not take the Bank's profits,

[18] Equity, profit, and net worth are denominated in bank florins. Standard practice in the literature would be to deflate these by a price index to obtain real values. We do not do this for two reasons. First, monthly price series are not available for this time period. Second, available data (van Zanden 2013) suggest that inflation was largely negligible in the Dutch Republic over most of the eighteenth century. Measured annual inflation averages 0.5 percent for 1700–92, and for our specific period of interest, 1781–92, annual inflation averages 0.4 percent. These rates are close enough to zero that it did not seem worthwhile to deflate with an interpolated monthly price series.

[19] As detailed in the next section, these items include future interest on Company anticipations and future interest from the Municipal Loan Chamber.

so that the entirety of such profits can be incorporated into net worth as a “deferred asset.”

For simplicity, our net worth calculations apply risk-neutral pricing to these income streams, using a constant risk-free annual interest rate of 3 percent. This is the average implicit rate for a bill of exchange (i.e., an unsecured debt claim) drawn on a high-quality counterparty (often a merchant bank) during our sample period, comparable to AAA commercial paper in a modern context.[20] Thus, with sufficiently positive net worth, the Bank could have hypothetically made its account holders whole by issuing debt at this favorable rate, assuming that the new debt holders would have first claim to the Bank’s income. Negative net worth is taken as an indication of the unsustainability of the Bank’s policies.

In addition to the Bank’s net worth, two other quantities of interest are the Bank’s *overall reserve ratio* and its *unencumbered reserve ratio*. The overall reserve ratio ρ (or “cash ratio” or “backing ratio”) is the ratio of all metal assets (encumbered plus unencumbered coin) to all account liabilities. The unencumbered reserve ratio ρ_u is the ratio of unencumbered coin to unencumbered accounts.

4. Data

The Bank of Amsterdam did not operate in an era of central bank transparency, and it never published balance sheets or income statements. However, many of the original records of the Bank are preserved at the Amsterdam Municipal Archives (AMA), and these can be used to reconstruct the Bank’s financial statements. To piece together the Bank’s history over the period January 1775–January 1792, data were collected from original documents.[21] Our data set

[20]Bills were unsecured and bore a certain degree of credit, liquidity, and foreign exchange risk; nonetheless, bills on prominent merchants were generally viewed as low-risk instruments. We use the bill rate as a benchmark rate rather than a rate on government debt, since the debt issues of the Dutch Republic and its provinces were rarely traded.

[21]These documents are the general ledgers of the Bank (AMA 5077/507–603), detailed breakdowns of the Bank’s master account (AMA 5077/1402–19), and accounts of the Municipal Loan Chamber (AMA 5077/38–40). The Bank’s master account is roughly comparable to the Federal Reserve’s System Open Market Account (SOMA) and analogous accounts at other modern central banks.

starts in 1775 to provide a five-year baseline of pre-crisis activity by the Bank and ends in 1792 because this is the last year that specialized data is available for the Bank's master account.

The balance sheet of the Bank involves twenty-two categories of assets and liabilities that can enter at a daily frequency, potentially yielding over 4,200 daily observations on the Bank's condition. For clarity in presentation, these data were condensed to more manageable series of 204 monthly observations. Because some income items only show up at a yearly frequency, income data were further condensed to annual series. Details of the data reconstruction are given in Quinn and Roberds (2014a). Agio data are taken from Gillard (2004) and exchange rate data are from Schneider, Schwarzer, and Schnelzer (1991, pp. 122, 150).[22]

4.1 Reconfiguration: 1781–83

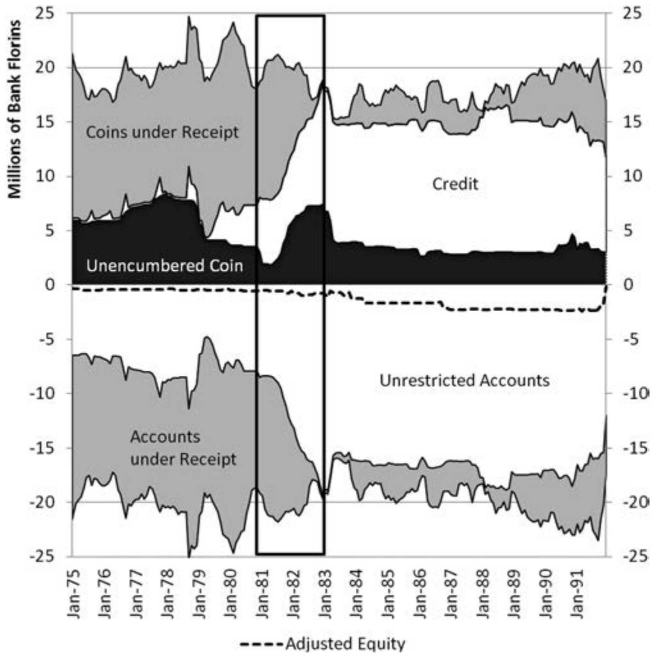
The Bank's initial loss of credibility occurred during the Fourth Anglo-Dutch War (declaration in December 1780; ceasefire in January 1783). This section traces the fundamental changes experienced by the Bank during the wartime period.

Figure 1 shows the Bank's balance sheet over our data sample. The aggregate size of the balance sheet stays roughly constant at about 20 million florins.[23] What changes markedly is the composition of the Bank's assets. Lending replaces coins held under receipt, and this dramatic change mostly occurred during the Fourth Anglo-Dutch War. Figure 1 shows that the stock of encumbered coin held at the Bank began falling with the threat of hostilities in 1780 and continued to fall throughout the course of the war. People rapidly abandoned receipts, a funding stream that had been continuously rolled

[22] These are rates in London and Hamburg for sight bills drawn on Amsterdam. These rates can move in slightly different directions because England was de facto on a gold standard at this time, while Hamburg was on silver. Missing observations in the data series were interpolated using a Kalman smoothing routine. Our exchange rate index is the geometric average of London and Amsterdam series, with the January 1781 index value normalized to 100.

[23] This is perhaps 10 percent of contemporaneous Dutch GDP, which does not seem excessive given the low interest rates inherent in the receipt system. By comparison, the central bank liabilities/GDP ratio for the United States was about 24 percent at year-end 2013.

Figure 1. The Bank of Amsterdam's Assets and Liabilities, 1775:M1–1792:M1



Source: Amsterdam Municipal Archives.
Notes: The Fourth Anglo-Dutch War is highlighted. Note that the top scale applies to the Bank's (negative) equity. Equity is adjusted by treating City loans as subtractions from equity rather than credits.

over for 100 years. The level of coins under receipt (and accounts under receipt) collapsed from 17 million florins in March 1780 to a mere 0.3 million by January 1783.

We conjecture that this collapse was a run motivated by fear that fiscal distress might imperil receipt claims. Account holders might have worried that the Bank would not promptly return high-value collateral, or that the Bank would retroactively hike the fees for redeeming a receipt. Such fears would have been amplified by uncertainty over the outcome of the war and worries that coins could be subject to military seizure. Functionally, the "repo run" observed on the Bank is the opposite of that experienced by Lehman Brothers in

2008, when repo investors in Lehman Brothers unwound positions for fear that funds sold might not be returned (Copeland, Martin, and Walker 2011). Here, people returned funds for collateral.[24]

The overall balance sheet, however, did not collapse, because the Bank simultaneously built its asset holdings with loans and open-market purchases.[25] During the war, the credit portfolio grew by 7.6 million and the level of unrestricted coins by 3.8 million. Both activities created unencumbered accounts, so total monetary liabilities remained relatively stable despite the run. This balance sheet reconfiguration remained the norm through the remainder of the sample.

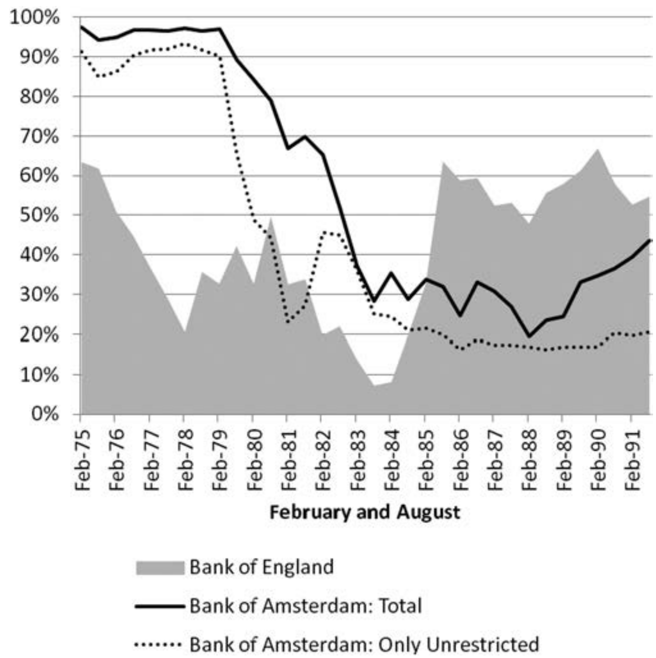
To underscore the transformation, figure 2 reports the Bank of Amsterdam's reserve ratio ρ over our sample period. From 1775 through 1779, the average was 95 percent, and even the ratio of unrestricted coins to unencumbered accounts ρ_u was 87 percent. For comparison, the Bank of England's average ratio was 42 percent over the same period (Clapham 1970a, pp. 296–97). By 1783, the Bank of Amsterdam's ratio fell to 37 percent, and the unencumbered ratio was nearly identical because so few coins were under receipt. At war's end, Amsterdam was still above London's ratio of 14 percent, but the remainder of the decade shows a new pattern. From 1785 through 1791, the Bank of England rebounded to an average of 55 percent while the Bank of Amsterdam retained an average of 31 percent. In other words, Amsterdam experienced a persistent shift from minimal to substantial fractional reserves.

Figure 3 details the composition of the Bank's new lending. Before the war, its credit activity was dominated by loans to the East India Company called anticipations. Anticipations were short-duration, seasonal loans secured on the return of fleets from Asia, typically toward the end of the year. The longest maturity for

[24]Like the 2008 run on Lehman, however, the run on the Bank was a "wholesale" phenomenon. The typical Bank purchase or sale of trade coins was for thousands of florins, well beyond the reach of an ordinary Amsterdam household at the time.

[25]Also, in July 1782, the City put coins worth 85,714.3 bank florins into the Bank. That sum is about one year's operating profit and is the only capital injection of coins that we know of over the Bank of Amsterdam's entire two-century existence.

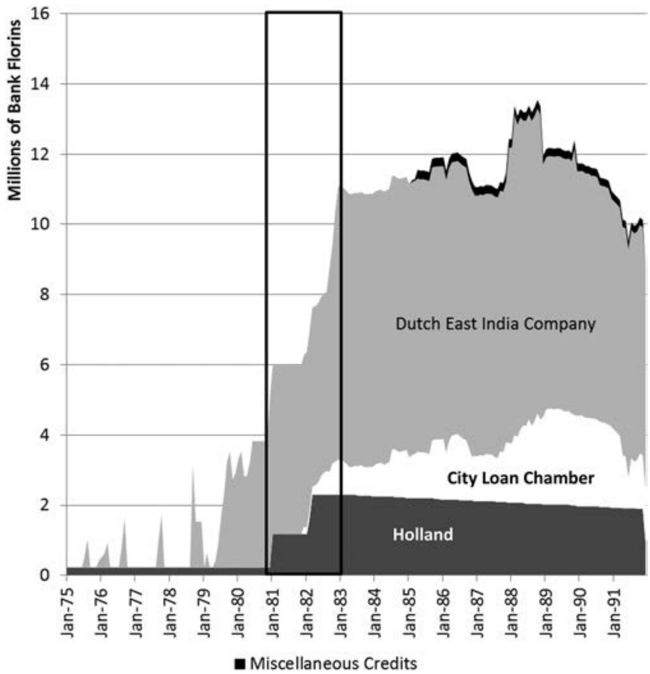
Figure 2. Reserve Ratios (precious metal to monetary liabilities)



Sources: Amsterdam Municipal Archives and Clapham (1970a, pp. 296–97).
Notes: The Bank of England's ratio is bullion over notes in circulation plus accounts. The Bank of Amsterdam's ratios are (i) total coins over total accounts and (ii) unrestricted coins over unrestricted accounts. The February and August dates conform to available Bank of England observations.

anticipations during the first three years of our sample was four months. In 1779, however, the Company delayed some repayments for over a year, after borrowing heavily. In 1780, the Company again borrowed heavily and failed to repay any of these anticipations, but it did manage intermittent interest payments. War then reduced shipments to and from Holland to their lowest levels in a century (de Korte 1984, appendix 8C). In February 1781, the largest division ("chamber") of the Company received permission from the province of Holland to suspend payment on its anticipations (Steur 1984, p. 116). The Bank stopped new lending to the Company in 1781, and

Figure 3. The Bank of Amsterdam's Loans Outstanding



Source: Amsterdam Municipal Archives.
Note: The Fourth Anglo-Dutch War is highlighted.

receipt holders began to "run" the Bank, with the extent of the run limited by the stock of outstanding receipts.[26]

In 1782, near the end of the run, the Company offered to convert its suspended debt into Company bonds that, in theory at least, were guaranteed by the States (Parliament) of Holland (de Korte 1984, p. 81). To participate in the swap, however, current creditors of the Company had to loan it an additional 50 percent. In May, the City formally sanctioned Bank participation in this conversion (van Dillen 1964, p. 417), and the Bank loaned the Company an additional

[26]Steur (1984) emphasizes that this period was marked by great legal uncertainty, stemming in part from the fact that contemporary Dutch bankruptcy law did not provide for potential insolvency of entities such as the East India Company; it was apparently seen as "too big to fail."

2.5 million. By year-end, total Company debt at the Bank was 7.7 million florins.[27]

During the war, the City also used the Bank to fund City lending to the Province of Holland.[28] The City took 2 million florins from the Bank and lent it to Holland in exchange for obligations paying 3 percent. Perhaps to reclaim some credibility for the Bank's balance sheet, the City committed to redirect the expected interest toward amortization. Instead of becoming the non-performing City loan, these debts became zero-interest obligations that were scheduled to be amortized over four decades.

The war also saw credit expanded through another channel, a City-operated lending facility known as the Loan Chamber (van Dillen 1964, p. 418).[29] The Loan Chamber was entirely funded by the Bank and provided credit to local merchants. By January 1783, this facility owed 1 million florins. After the war, the Loan Chamber's debt rose to over 2 million florins and became an important source of income for the Bank.

From figures 1 and 3, we see lending to the East India Company and to the Loan Chamber directly created unencumbered account balances to replace the loss of balances matched by a receipt. The Bank added more unencumbered balances with aggressive open-market operations. From May 1781 to July 1782 (the nadir of the receipt run), purchases added 7.1 million in unencumbered balances to the balance sheet. Besides creating bank money, this incoming coin more than offset the coins removed by the City. The City's depletions caused the Bank's adjusted equity (i.e., equity net "loans" to the City), which started off slightly negative at –482,001 florins

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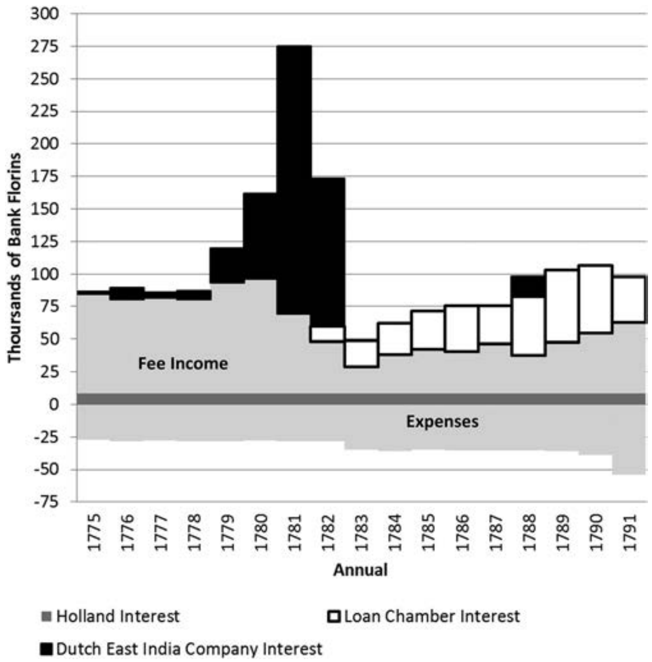
[27]Even abstracting from concerns about credit risk, the 1782 debt swap was potentially problematic for the Bank, since it resulted in a significant maturity mismatch between its assets (which now included many long-term bonds) and its liabilities (in theory, readily convertible to trade coin at a stable agio).

[28]The Bank started the war already holding a small perpetual Holland annuity with a principal of 227,000 bank florins.

[29]The Municipal Loan Chamber was originally created in response to the financial crisis of 1772–73 (Breen 1900, de Jong 1934). Creation of the Loan Chamber was necessary because direct lending to merchants was seen as a violation of the Bank's charter. At that time the Loan Chamber saw only light use, and it was closed within a few months. Loss of credit availability during the Fourth Anglo-Dutch War resulted in the Chamber's reopening.

Figure 4. The Bank of Amsterdam's Income and Expenses



Source: Amsterdam Municipal Archives.

in January 1780, to decline to –778,200 by the end of the war and to –2.3 million by 1791.

Finally, the rapid restructuring of the balance sheet altered the Bank's flow of income: earnings flipped from being primarily derived from people using the receipt facility to being heavily reliant on interest from loans. Figure 4 breaks down the Bank's income by source and shows that before the crisis, the Bank made most of its revenue from usage fees. The run greatly reduced fee income, so interest income became dominant. Massive lending to the East India Company initially resulted in a substantial rise in the Bank's profits—until the Company stopped paying. Thereafter, interest from the Loan Chamber rivaled fee income.[30]

[30]Low interest rates implicit in the receipt system and non-performance of credits to the East India Company cause the Bank's profitability to be quite low

4.2 Decline: 1784–89

The armistice of January 1783 effectively ended the Fourth Anglo-Dutch War (the treaty arrived in May 1784), but peace did not return the Bank to its pre-war condition. This section describes the extent of the problems faced by the Bank, and its attempts at recovery before the outbreak of a second crisis in 1790.

The disruptions of the Fourth Anglo-Dutch War to the Company's operations were severe, and as a condition of peace, the British gained permanent free trade access to the Dutch East Indies, undermining an important source of the Company's profit. Costs to equip outbound ships exceeded the Company's revenue from traded goods in every year from 1780 until the end of the Dutch Republic in 1795 (de Korte 1984, p. 85). At war's end, the Company's total debt was 38 million guilders (20 percent held by the Bank; de Korte 1984, p. 87 and appendix 1E), and subsequent government injections inflated the Company's total debt to 91 million guilders by 1790, by which time 81 million was in arrears (de Korte 1984, p. 84).

The immediate consequence of this for the Bank was that its largest debtor completely failed to perform for three years. By early 1783 this situation began to erode the value of the bank florin (figure 5). A directive from the governing commission of the Bank, dated April 1782, instructed Bank employees to try to hold the agio between 4 and 5 percent through open-market operations, when these could be undertaken without significant losses to the Bank (van Dillen 1925, pp. 433–34). By early 1783, however, figure 5 shows that the agio on the bank florin was already trading in the 3 percent range. Moreover, the foreign exchange value of the florin fell by about 5 percent over the course of the war. The Bank responded to these depreciations through a "tightening operation": selling 3.5 million florins' worth of guilder coins into the market during the first half of 1783. This policy seems to have had some beneficial effect: by January 1783 the slide in the agio abated, and by year-end the agio briefly returned to the 4 percent range. Trade coins trickled back into the Bank (figure 1).

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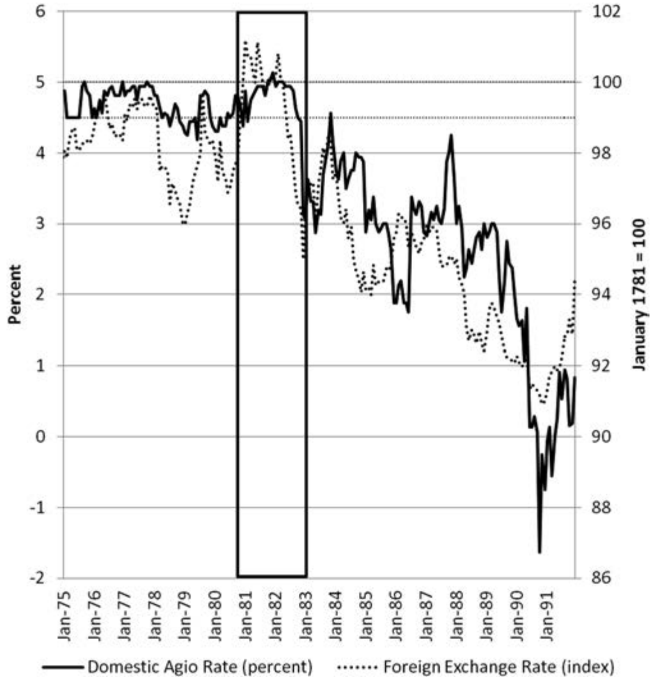
compared with modern central banks, with an average return on assets of only 0.38 percent over our sample. For comparison, the average return on assets for central banks during the Great Moderation was about 1.5 percent (Klüh and Stella 2008).

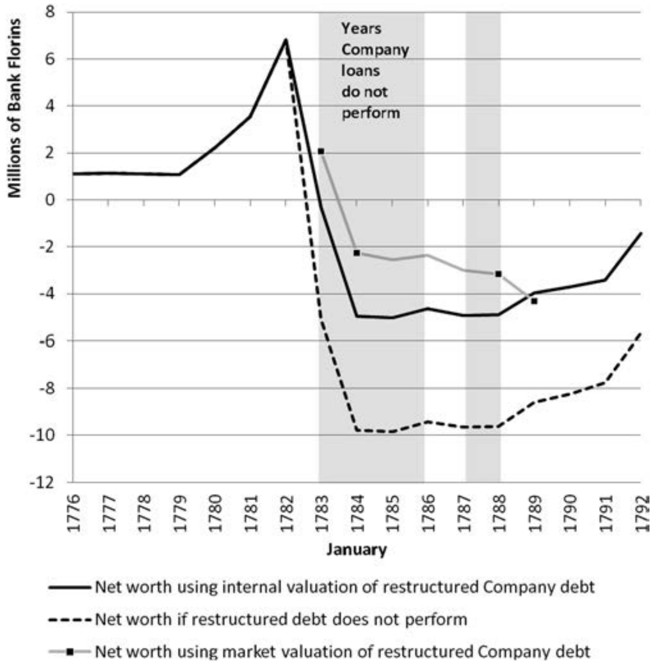
Figure 5. The Bank Florin Agio and Exchange Rate



Sources: Schneider, Schwarzer, and Schnelzer (1991), and Gillard (2004).
Note: The Fourth Anglo-Dutch War is highlighted. The agio's traditional trading range is horizontally highlighted at 5 and 4.5 percent.

Yet the Bank could not sustain this policy. By the summer of 1783, the Bank's stock of unencumbered coins fell to 4.4 million florins, leaving its overall reserve ratio at a perilously low 28 percent (figure 2). This ratio had been 97 percent just four years earlier. Open-market sales of silver were abruptly interrupted. The Bank's problems, however, extended beyond illiquidity, for the continued non-performance of loans to the Company, combined with the cumulated effects of its earlier monetary expansions, caused the Bank to become policy insolvent. As long as its profits were taken by the City, the Bank had no way to offset its losses on loans to the Company. And even if the Bank had started to retain all of its earnings, it is doubtful that these would have proved sufficient to return the Bank to solvency.

Figure 6. The Bank of Amsterdam's Net Worth by Scenario



Sources: Amsterdam Municipal Archives and authors' calculation.
Note: The net worth using market valuations relies on auction prices of new Company debt issued in March 1783, December 1783, April 1788, and February 1789, and linear interpolations between auction dates.

4.2.1 Policy Insolvency

Figure 6 charts the evolution of the Bank's net worth in January of each year in the sample under different scenarios. As noted above, calculation of net worth requires at each date an adjustment for "franchise value," i.e., for the value of future net income not reflected in book assets.

The net worth estimates also require an evaluation of the Bank's credit portfolio. The Bank recorded loans as their principal due, but this can differ substantially from what an investor might pay for the Bank's long-term assets. For example, the 1781 and 1782 loans to the City did not pay interest, so we have revalued them as the present value of the expected amortization payments (see Quinn and Roberds 2014a for details). The more difficult valuation is the restructured Company debt that did not pay interest *and* had a substantial credit risk. So figure 6 reports how insolvent the Bank of Amsterdam became, based on three ways of assessing the restructured Company debt held by the Bank.

Our first estimate of net worth applies four price observations from auctions of new Company debt.[31] There was little or no secondary market for these instruments, so such data points are rare. The prices were the percent of principal the buyer was willing to pay, but the maturities of the bonds were not recorded, so we assume that they were similar to the thirty-three-year maturity held by the Bank.[32] If the auctioned debt was actually of a shorter maturity, then the implied default probability would be greater, and the insolvency worse, than that shown in figure 6. The auction prices suggest that the Bank's insolvency in 1784 was –2 million florins, but market perceptions of the Company worsened over time, causing the Bank's insolvency to double by 1789. The decline corresponds with years the Company did not pay anything to the Bank, or presumably to other creditors.

A second approach views the restructured debt from the Bank's internal perspective. When the Company did start making payments again, the Bank received only amortization payments. The internal valuation line uses this as the expected reality of the restructured debt. It calculates the present value of these payments for each year starting in 1783, and it produces the Bank's net worth if the Company met its thirty-three-year amortization schedule but never paid interest. This view of the restructured debt puts the net worth below –4 million florins half a decade before the market does.

Finally, as a lower bound, a third approach (dashed line in figure 6) reports the Bank's net worth if the restructured debt fails entirely and irrevocably. Under this scenario, the Bank's net worth goes to almost –10 million in January 1784. This would have been the most prescient valuation, since the Company was in default over most of

[31]These data were generously supplied by Christiaan van Bochove and Joost Jonker.

[32]Other bonds mentioned in de Korte (1984, p. 87) were of a similar maturity: thirty-three years in 1781 and thirty years in 1791.

our sample, and completely so after seizure of its ships by the British navy in 1795 (de Korte 1984, p. 91).

Thus, under all three scenarios depicted in figure 6, the Bank was insolvent by 1784. The actual shortfalls faced by the Bank would have been larger than those shown in the figure, since the City never fully gave up Bank profits as a source of revenue.

4.2.2 Attempts at Self-Repair

Although the Bank did not publish its balance sheets, the market priced the Bank's weakness over the rest of the 1780s. The agio and the foreign exchange rate continued to decline (figure 5) and the Bank did not engage in defensive open-market operations. And new initiatives indirectly acknowledged the Bank's credibility problem. For example, the City attempted to limit dividends beyond yearly profit by treating them as actual loans. In 1783, the City opened a line of credit with the Bank and repaid 800,000 florins (with interest!) of the 1.4 million borrowed. The effort, however, soon ended as the remaining principal returned to non-performance in 1784. Over the rest of our sample, the City took out an additional 943,714 florins in non-performing loans.

The Bank's accounting treatment of Company debt also shifted in 1783. The Company suspended all payments for three years and the Bank stopped accruing interest on Company debt. The Bank, however, rolled over, or "evergreened," the debt principal. When a 3 percent coupon payment did show up 1786, after a three-year abeyance, the City then used the funds to shift bonds from the Bank's balance sheet and, presumably, to the City's balance sheet. From the Bank's perspective, the process slowly amortized the principal but ignored interest due. The process led to an incremental improvement of the Bank's net worth under the second scenario shown in figure 6 (solid black line).[33]

Amortization reduced the Bank's vulnerability to future Company non-performance at the expense of immediate gains. If the Bank instead accounted for Company payments as interest income

[33]Resumption of payments seems to have allowed the Bank to reopen some short-term lending to the Company. The Bank made three new loans, each of which the Company repaid in full. One loan, a 1788 loan for 700,000 florins, was even repaid with interest.

on a perpetual debt, then the Bank's net worth would have increased substantially: discounted at 3 percent, these payments would have added a present value of 7.65 million. The City would have benefited as well, by taking the income as dividends. Instead, principal was reduced. As a result, the amount of potential insolvency was made less each passing year. This amortization policy would have helped the Bank only *if* the Company's long-term credibility were highly suspect. At the time, Holland was subsidizing the Company with vast sums, and the Company's unsubsidized outlook remained bleak. With this policy, the City chose to slowly reseparate the bank florin from the Company rather than accept a florin built on a massive, undiminishing Company debt. This variation on a strategy of "extend and pretend" was, however, insufficient to remedy the Bank's insolvency.

Sustained growth in receipt balances (figure 1) brought a different sort of relief for the Bank in 1789. This coincides with the political instability of the French Revolution, but we cannot track where coins are coming from. Still, the influx of new coin types from Brabant, Prussia, Russia, and Sweden suggest a new pattern at work. Also, the bank florin continued to weaken both in terms of the agio and relative to London and Hamburg, so the inflows are unlikely to have come through those traditional channels. A contemporary observer attributed the florin's weakness to sovereign loans made by Amsterdam merchant banks to Russia, Sweden, and Austria in the amount of 40 million florins (van Dillen 1964, p. 420).

4.3 Crisis: 1790–91

The appearance of another crisis in 1790 led the Bank to undertake a series of unconventional policies designed to restore its credibility. This section describes the nature and extent of these policies.

Beginning in 1790, the Bank attempted to use the renewed inflow of trade coins to stabilize the rest of the Bank and halt the decline in the agio. First, the Bank acquired encumbered silver coins by purchasing receipts on the market instead of purchasing coin outright as it had in the past. From June 1790 to May 1791, the Bank converted 3.7 million in silver coin from encumbered to unencumbered. The logic behind this operation may have been to reduce the scope of a possible run by diminishing account holders' ability to redeem

Bank balances in coin. From a modern perspective, however, a policy of purchasing receipts is seen as the Bank buying a large number of put options on its own currency. Not surprisingly, this intervention proved ineffective.

The agio dropped below zero by November 1790 (figure 5). In a desperate move to halt the florin's slide, the Bank then offered to redeem the balances of large account holders in silver bars at a price of 26.75 florins per silver mark (van Dillen 1964, p. 421). This was a de facto devaluation of 9–10 percent over the traditional (implicit) silver value of the florin, of 24.1–24.25 florins per mark. No one took the Bank up on this offer. Instead, in January 1791, prominent account holders filed a formal protest with the City, accusing the Bank of having increased its money stock in an "unnatural fashion" without "backing of saleable specie or coin material" (van Dillen 1964, p. 422). The protesters demanded that all accounts be made directly convertible to (silver) specie at the former value, as had occurred prior to the introduction of the receipt system.

The data show that the Bank made two additional policy moves in early 1791. The first of these was to raise the bank price of gold coins by 2.5 percent, effectively a reduction in the Bank's "haircut" when people used gold as collateral: a backdoor devaluation. The second move, an apparent response to the account holders' protest, was to set a price floor for the agio by using unencumbered silver coins to fund a traditional (i.e., non-receipt) process of withdrawal, an option that has been in abeyance for over a century. The Bank made the new facility available only to dealers in the agio market and set the initial withdrawal agio to –1 percent. This means people got 99 current guilder coins per 100 bank florins in account. At that below-market rate (figure 5), dealers withdrew 344,000 bank florins in two weeks. Perhaps feeling overly confident, the Bank then raised the withdrawal agio to zero percent (just above market rates), and 1.6 million left in two weeks. Belatedly realizing that it had been funding a run, the Bank abandoned this effort to stabilize the agio in mid-February 1791. The Bank had proved unable to restabilize itself.

4.4 Recapitalization: 1791–92

Over an eight-year span beginning in 1783, the Bank was too far from solvency to reestablish credibility. Efforts to introduce a meaningful,

Table 5. Recapitalization of April 1791–January 1792 (quantities are bank florins)

	Full Company Performance	No Company Perfomance
Initial Equity	–2,303,300	–8,805,800
Initial Net Worth	–40,477	–6,542,977
Change in Accounts (Liabilities)	–6,076,893	
Balance Sheet Effects:		
Change in Equity due to Recapitalization	+2,418,438	
Other Changes in Balance Sheet:		
Change in Loans (Assets)		
Holland (Performing)	–952,381	
Loan Chamber (Performing)	–999,741	
East India Company (No Interest)	0	
Change in Coins (Assets)	–1,706,333	
Equity after All Changes	–145,590	–6,418,590
Net Worth after All Changes	1,310,865	–4,962,135

Sources: Amsterdam Municipal Archives and authors' calculation.

if devalued, peg for the florin failed. Efforts to improve loan performance were likewise unsuccessful. Indeed, the City continued to take operating profits, and more, from the Bank. Under pressure from market participants, the City finally attempted to recapitalize the Bank in 1791. This section describes the recapitalization.

On February 17, 1791, the City Council authorized a bond issue of 6 million florins (van Dillen 1964, p. 422) for recapitalization, with prominent merchant banks agreeing to support the issue. Calculations shown in figure 6 suggest that this was, on its face, a reasonable move given the extent of the Bank's accumulated losses. Examination of the Bank's ledgers confirms that from April 1791 through January 1792, the City gave over 6 million florins in balances to the Bank for destruction.

The Bank's reconstructed balance sheet shows why the recapitalization did not succeed in restoring the bank florin. The City did not restrict the use of the injected funds to restoring equity. As table 5 shows, 40 percent went to increasing the Bank's equity, but the remainder was diverted. Almost one-third went to retire self-amortizing loans secured by Holland bonds and by interest-earning loans to the City Loan Chamber; 28 percent was taken out by the City as coin. During the operation, the agio appreciated 1.4 percentage points (from –.56 to .84) and the exchange rate appreciated 2.8 percent. The Bank's reserve ratio rose to 48 percent, a ratio similar to the Bank of England's. At the same time, the non-performing East India Company debt remained, and this means that the Bank was insolvent with a net worth of –4.96 million florins under the increasingly probable no-recovery scenario. Again, even that estimate of net worth assumes the City would have stopped taking all future earnings, which seems unlikely given the City could not resist taking 1.7 million in coin from the Bank's recapitalization.

4.5 Epilogue: 1793–95

The Bank of Amsterdam's decline did not stop in January in 1792. Unfortunately, the records of the Bank's master account are not available after that date, so we are unable to continue our data reconstruction. The basic story of the Bank's further decline is described in the literature, however, and table 6 summarizes that story using 1793–95 fiscal year-end (January) data compiled by van Dillen (1934, p. 122).

By this time, the international strength of the bank florin was gone, and its exchange rate continued to deteriorate. Some metal returned to Amsterdam in late 1792, and van Dillen (1964, p. 425) attributes this to an influx of Spanish silver and to continued capital flight from the consequences of the French Revolution. The agio briefly climbed to the 2 percent range in late 1793 after war broke out with France, only to return to negative territory by August 1794. Encumbered coin left the Bank and the Republic soon thereafter. The bank florin departed the world stage when the French army reached Amsterdam in January 1795.

5. Conclusion

The above calculations indicate that accommodative policies pursued by the Bank of Amsterdam over 1781–83 caused it to become

Table 6. The Bank of Amsterdam, 1792–95

Date	Exchange Rate Index (1781:M1 = 100)	Agio (Percent)	Coin (Bank Florins)	Reserve Ratio (Percent)	Profits and Losses (Bank Florins)
1792:M1	94.4	0.84	8,408,441	48	68,696
1793:M1	93.9	0.81	13,238,010	60	–27,955
1794:M1	90.7	1.91	8,471,075	48	–10,402
1795:M1	85.9*	–25.00	2,506,046	21	–155,314

Sources: van Dillen (1934, p. 122), Schneider, Schwarzer, and Schnelzer (1991), and Gillard (2004). 1792 financials are from authors' calculations.
Note: * denotes December 1794 value.

policy insolvent by 1784 at the latest. The extent of the insolvency remained hidden from public view, but the markets sensed that something was wrong and kept the bank florin under pressure until its full collapse in 1795.

We conclude by considering the implications of this episode for modern central banks. The florin's downfall illustrates three types of policies that have been identified in the literature as detrimental to central banks' net worth and credibility more generally. The Bank's first policy error (see, e.g., Cukierman 2011, p. 36) was its decision to support a large, bankrupt government-sponsored enterprise (the Dutch East India Company) while trying to maintain an indefensible policy target (the agio peg of 4–5 percent). Negative impacts on the Bank's net worth were amplified by a second policy error (Archer and Moser-Boehm 2013), which was the City of Amsterdam's practice of keeping Bank profits to itself and allocating losses to the Bank. The first two mistakes eroded the net worth of the Bank until a fiscal bailout offered the only feasible way to restore the Bank's reputation. A third policy error, of inadequate fiscal backup (Sims 2004), was manifested in the City's botched recapitalization of 1791–92. Applied in isolation, any of these policies would have worked to undermine the Bank. A key lesson seems to be that a combination of all three was particularly toxic.

Was the florin's collapse inevitable? To some extent "yes": the groundwork for the collapse was laid as early as 1683 with the introduction of the receipt system and the subsequent decision by the City to regularly remove the Bank's profits (see Quinn and Roberds 2014b and section 3 above). This system worked well for almost 100 years, however, in part because the strong demand for Bank funds at the receipt window obscured the Bank's negative equity position. Seasonal credit exposures to the Company were small and unproblematic, and the need for any fiscal support from the City must have seemed remote. Confidence in the institutional structure of the Bank was reinforced by Amsterdam's experience in earlier crises, in 1763 (Quinn and Roberds 2015) and 1772–73 (Breen 1900, Koudijs and Voth 2014), where use of the receipt window ballooned as panicked market participants demanded extraordinary amounts of Bank money. In these episodes, people ran to the Bank rather than from it.

Modern central bank accounting shows that despite these earlier successes, by 1784 the Bank's fiscal capacity had been breached. At the time, however, the intractability of this situation may not have been so apparent. The 1781–83 receipt run (see figure 1) in particular may have appeared to the Bank's managers as a one-off shock from which recovery was imminent. The Bank's participation in the 1782 debt swap and its reluctance to seek fiscal support suggest an unwillingness or inability to grasp the severity of its predicament. From an ex ante perspective, it may thus be a bit unfair to judge the Bank on an inadequate response to an almost unimaginable "tail event." But central banking is an activity in which the unthinkable can sometimes come to pass.

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What Is Learned from a Currency Crisis, Fear of Floating, or Hollow Middle? Identifying Exchange Rate Policy in Crisis Countries*

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This paper develops a new methodology to infer the de facto exchange rate regime, based on a structural VAR model with sign restrictions. The methodology is applied to data from eleven emerging markets that experienced a currency crisis. The main findings are as follows: (i) to be consistent with the "hollow middle" hypothesis, many countries moved toward hard pegs, such as dollarization and a currency board, or more flexible exchange rate arrangements that are close to the free float in the post-crisis period; and (ii) the cases where a country overstates its exchange rate flexibility (including the case of "fear of floating") are found in all samples, but such cases tend to be less frequently found in the post-crisis period than in the pre-crisis period.

JEL Codes: F33, E52, F31, C32.

1. Introduction

Many countries have experienced a currency crisis and economic turbulence, including Europe (1992), Mexico (1994–95), East Asia

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(1997), Russia (1998), and Argentina (2002). With the onset of a currency crisis, most of these countries adopted highly managed exchange rate arrangements. As a result, there is the notion that the tight exchange rate arrangements adopted in each country are at least partly responsible for the currency crisis. Consequently, lively discussions on the choice of the exchange rate regime have followed.

Eichengreen (1994) suggests that highly managed exchange rate arrangements are vulnerable to international capital flows. Thus, intermediate regimes, including a soft peg, would disappear in a world with integrated capital markets. The only viable choices would be two extreme exchange rate arrangements: free float and "hard peg." These choices would include currency boards, dollarization, and a currency union. This view is known as the "hollow middle" hypothesis (Eichengreen 1994) or the "bipolar view" (Fischer 2001).[1]

European monetary unification confirms the bipolar view since a currency union can be regarded as a polar regime. However, experience of emerging markets is more diversified, and it does not uniformly support this bipolar view. Although changes toward polar regimes are seemingly observed based on what each country officially states or the country's de jure classification of the exchange rate regime (for example, see Fischer 2001), each country's official statement may be different than what the country actually does. Calvo and Reinhart (2002) find that by inferring the exchange rate policies in each country from the actual data on the exchange rate and policy instruments (that is, de facto arrangements), most countries that say they allow their exchange rate to float do not. Calvo and Reinhart (2002) conclude that there seems to be an epidemic case of "fear of floating."[2] This possible discrepancy between de jure and de facto exchange rate arrangements has been well represented in previous debates. For example, McKinnon (2000) and Mussa et al. (2000) argue that a few years after a crisis, Asian countries that had the crisis reverted back to highly managed exchange rate arrangements (although they claimed free float) and these countries raised concerns of possible repetition of the crisis.

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[1]See also Obstfeld and Rogoff (1995) and Krueger (2000) for this view.

[2]Levy-Yeyati and Sturzenegger (2005) also confirm "fear of floating" by classifying the de facto exchange rate regime of each country based on the data.

This paper contributes to the literature on the transition of exchange rate arrangements and de facto exchange rate arrangements in two aspects. First, this paper develops a de facto measure of exchange rate arrangements by using a structural VAR (vector autoregression) model, which resolves a few problems with previous methods. Second, this method is applied to countries that experienced a crisis during the 1990s and the 2000s in order to investigate how these countries change the exchange rate arrangement after the crisis and to shed some light on various issues concerning de facto exchange rate arrangements and the transition of exchange rate arrangements.

While past studies often investigated not only crisis countries but also non-crisis countries, this study has focused on countries that have experienced a severe crisis. These countries are the main victims of the crisis. They are the ones who have been deliberating on the exchange rate regime choice. These countries have made choices regarding the exchange rate regimes after realistically considering the possibility of a future crisis. On the other hand, the choices of other countries are likely to be more superficial. Other countries may simply keep their current exchange rate arrangements, or their choice may involve consideration of some aspects other than the crisis. In other words, it would be interesting to see what these countries learned about exchange rate arrangements after their experience of a severe crisis. As examples, did these crisis countries move to polar regimes that were less vulnerable in integrated capital markets? Were these countries reluctant to publicly announce their highly managed exchange rate arrangements? This study also has focused on relatively recent crisis episodes, since various views on exchange rate regimes (such as the vulnerability of the soft peg) have become widely known in relatively recent years. Eleven cases are considered. These cases include five Asian crisis countries.

Following Calvo and Reinhart (2002), a number of previous studies construct de facto regime classifications (e.g., Baig 2001; Bubula and Ötker-Robe 2002; Ghosh, Gulde, and Wolf 2003; Hernandez and Montiel 2003; Levy-Yeyati and Sturzenegger 2005; and Reinhart and Rogoff 2002). Many previous studies, including Calvo and Reinhart (2002), rely on information on the volatility of the exchange rate (changes) and the policy instruments (changes) such as foreign exchange reserves (changes) and the interest rate (changes).

If the policy authority actively stabilizes exchange rate movements by adjusting the policy instruments, the exchange rate changes would be small while the policy instrument changes would be large. Based on this idea, past studies often classified regimes with less volatile exchange rates (changes) and more volatile policy instruments (changes) as having less flexible exchange rate arrangements.[3]

However, such classification methods have a drawback. The policy instruments may change in the absence of the policy authority's intention to stabilize the exchange rate. For example, the interest rate may be changed in support of other policy objectives rather than for just the purpose of stabilizing the exchange rate (i.e., stimulating output). Foreign exchange reserves, for instance, may change due to fluctuations in valuation, interests accrual, and passive interventions in order to fulfill government transactions or orders. Such changes in policy instruments (and the resulting changes in the exchange rate) are not relevant to exchange rate stabilization. Although past studies have included such changes, these changes should be excluded when inferring de facto exchange rate arrangements. In a sense, the problem arises from using *unconditional* data that comprises both the movements originating from shocks to the exchange rate that policy instruments react to and the movements originating from shocks to the instruments that affect the exchange rate, although only the former contains the relevant information. From another perspective, past studies have used information from both the policy reaction function (the policy authority's reaction of policy instruments to the exchange rate, in order to stabilize the exchange rate) and the foreign exchange market equation (that shows how the policy instruments affect the exchange rate). However, only the former is relevant. In other words, although there is a simultaneity problem between the policy instrument and the exchange rate (or between the reaction of

[3]Calvo and Reinhart (2002) characterized various countries based on three variables (the exchange rate, reserves, and the interest rate) without providing an exact classification of countries. On the other hand, Ghosh, Gulde, and Wolf (2003) and Reinhart and Rogoff (2002) provide an exact classification, but the inference is based on the exchange rate only. Levy-Yeyati and Sturzenegger (2005) provide an exact classification based on two variables (the exchange rate and reserves). The current paper provides the estimated reaction function and some test statistics to infer the exchange rate policy based on three variables (the exchange rate, reserves, and the interest rate) and provide a classification.

policy and the effects of policy), it is not properly accounted for in past studies.

Structural VAR models are a natural fit in addressing this problem since structural VAR models can be used to identify different types of structural shocks (and structural equations) and also to construct the *conditional* data in the presence of only one type of structural shock. To separate the two types of shocks, this study imposes sign restrictions on impulse responses by modifying Uhlig's (2005) methodology. The two shocks imply different sign restrictions on the responses of the exchange rate and policy instruments. An (exogenous) increase in the foreign exchange reserves (or a decrease in the interest rate) would lead to an exchange rate depreciation. On the other hand, an (exogenous) exchange rate depreciation would lead to a decrease in the foreign exchange reserves (or an increase in the interest rate) when the policy authority stabilizes the exchange rate. Based on the estimated impulse responses to the latter shocks, dynamic policy reaction functions are formally derived—instead of simple descriptive statistics, as used in some past studies—in order to infer de facto exchange rate arrangements in each country.

The main findings are as follows. The cases where a country overstates its exchange rate flexibility (including the case of "fear of floating") are often found, but such cases tend to be less frequently found in the post-crisis period than in the pre-crisis period. Based on de facto classification after correcting for such cases, most countries adopted intermediate regimes in the pre-crisis period, but a majority of countries adopted a hard peg or the exchange rate regime that is close to a free float such as Australia's. It is especially interesting that four Asian crisis countries achieved an exchange rate flexibility that is close to that of Australia's in its post-crisis period, although some past studies argued that these four countries reverted back to a highly managed exchange rate policy. Overall, the tendency of a country's overstating its exchange rate flexibility does not overturn the general conclusion on exchange rate regime transitions based on de jure classification; countries move to bipolar regimes.

The rest of the paper is organized as follows. Section 2 explains the methodology developed in this paper. Section 3 analyzes exchange rate arrangements and discusses various issues on exchange rate arrangements. Section 4 discusses some extended experiments and compares the methodology in this study with that of Calvo and Reinhart's (2002). Section 5 concludes with a summary of findings.

2. The Methodology

The methodology starts from the most parsimonious model, since the model is applied to short time-span data. Since the number of parameters to be estimated in VAR models increases geometrically as the number of variables increases, a large VAR model often suffers from a low degree of freedom. The most parsimonious model includes only two variables—the exchange rate changes and changes in one policy instrument. The number of parameters to be estimated in the two-variable model is relatively small, which helps ensure that the model can be successfully applied to a short time span.

As emphasized by Levy-Yeyati and Sturzenegger (2005), the textbook definition of the fixed exchange rate regime is the regime in which changes in foreign exchange reserves are aimed at reducing the volatility of the exchange rate while the flexible exchange rate regimes are characterized by substantial volatility in the exchange rate with relatively stable reserves. Therefore, the exchange rate and foreign exchange reserves are included in the model in order to infer the exchange rate arrangements.

In addition to the foreign exchange reserve, another important policy instrument, the interest rate, is also often used to control the exchange rate. Consequently, past studies, such as that of Calvo and Reinhart (2002), have also examined interest rate changes. Therefore, a two-variable model with the exchange rate and the interest rate is also constructed in order to complement the first model.

As is usual in structural VAR analysis, the structural representation is identified by imposing some restrictions on the estimated reduced form. The reduced-form VAR equations for the first model are

$$\begin{bmatrix} \Delta E_t \\ \Delta FR_t \end{bmatrix} = \begin{bmatrix} A_{11}(L) & A_{12}(L) \\ A_{21}(L) & A_{22}(L) \end{bmatrix} \begin{bmatrix} \Delta E_{t-1} \\ \Delta FR_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{E,t} \\ \varepsilon_{FR,t} \end{bmatrix}, \tag{1}$$

where E is the log of the exchange rate; ΔFR is the ratio of the changes in foreign exchange reserves to monetary base of the previous period; $A(L)$s are polynomials in the lag operator $L; \varepsilon_E$ and

ε_{FR} are the residuals in each equation, which are assumed to be Gaussian random variables; ε is a two-by-one vector of residuals, $\varepsilon = (\varepsilon_E\ \varepsilon_{FR})$'; and $\text{var}(\varepsilon) = \Sigma$. For simplicity of exposition, the constant term is dropped in equation (1). This study uses the log-difference or the difference of each variable (instead of log-level or level) for the following reasons. First, most past studies, such as the studies of Baig (2001), Calvo and Reinhart (2002), Hernandez and Montiel (2003), Levy-Yeyati and Sturzenegger (2005), and Reinhart and Rogoff (2003), have used the percentage changes (or difference) instead of log-level, or level. This helps make the results of this study comparable to past studies. Second, in most countries, the hypothesis of a unit root in log of the exchange rate and the hypothesis of a unit root in the ratio of foreign exchange reserve to monetary base are not rejected at the conventional significance level based on conventional unit-root tests like the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Third, there are some cases of continuously falling or rising exchange rates such as a crawling peg regime. In such cases, the log-difference of the exchange rate may be more appropriate than log-level.

On the other hand, although some studies, such as Calvo and Reinhart's (2002), used percentage changes in foreign exchange reserves, this study uses the changes in foreign exchange reserves as a percentage of the monetary base in the previous period, as the study of Levy-Yeyati and Sturzenegger (2005) did, for the following reason. The level of foreign exchange reserves may change over time and with countries. For example, Asian countries that had a crisis accumulated a substantial amount of foreign exchange reserves after the crisis. The accumulation of foreign exchange reserves was far faster than development in the countries' general economic activities or monetary environment. In that case, a 1 percent change in foreign exchange reserves may have smaller effects on the exchange rate in the pre-crisis period than in the post-crisis period. To correct this problem, the responses of reserve changes are calculated as a percent of the monetary base of the previous period, since the size of a monetary base may be a reasonable proxy for development in a monetary environment.

As discussed in the Introduction, some policy instrument changes (and the resulting exchange rate changes) are not related to exchange rate stabilizing policy actions. We are interested in only the policy instrument changes that are the results of (exchange rate stabilizing) policy reactions to exchange rate changes. This objective can be achieved in the two-variable model by separately identifying two orthogonal structural shocks: the (structural) shocks to the exchange rate (that foreign exchange reserves react to stabilize the exchange rate), and the (structural) shocks to foreign exchange reserves (that affect the exchange rate). However, popular identification methods that impose zero restrictions on the contemporaneous structural parameters, (developed by Bernanke 1986; Blanchard and Watson 1986; and Sims 1980, 1986;) and that impose zero restrictions on the long-run effects (developed by Blanchard and Quah 1989) are difficult to apply in this case. Both structural shocks are likely to affect both variables contemporaneously, so that imposing zero restrictions on contemporaneous parameters is not feasible.[4] In addition, an imposition of any long-run zero restrictions in the current model does not seem to be firmly supported by theories.

To separately identify the two types of structural shocks, sign restrictions are imposed on impulse responses. First, a positive shock to foreign exchange reserves would lead to exchange rate depreciation (or an increase in the exchange rate); buying foreign currency, selling domestic currency, and building up foreign exchange reserves would lead to a weaker currency value, i.e., exchange rate depreciation. Second, a positive shock to the exchange rate (or exchange rate depreciation) would lead to a decrease in the foreign exchange reserves when the policy authority stabilizes the exchange rate. This is because a decrease in the foreign exchange reserves would appreciate the exchange rate to offset the initial depreciation. That is, shocks to foreign exchange reserves move the exchange rate and the foreign exchange reserves in the same direction, while shocks to the exchange rate move two variables in opposite directions. This study imposes such restrictions only on the impact responses, as it is more difficult to justify the signs of the lagged responses.[5] To implement

[4]In the large-scale model that is estimated over a long sample period, the two types of shocks can be separated with short-run zero restrictions by using other variables as instruments. For example, see Kim (2003, 2005).

[5]For example, a positive foreign exchange reserve shock would depreciate the exchange rate on impact, but the foreign exchange reserve might decrease in the next period if the policy authority tries to offset the initial exchange rate depreciation.

such identification, this study modifies the method developed by Uhlig (2005).[6] See the appendix for details.

The structural-form equations in the VMA (vector moving average) form are

$$\begin{bmatrix} \Delta E_t \\ \Delta FR_t \end{bmatrix} = \begin{bmatrix} C_{11}(L) & C_{12}(L) \\ C_{21}(L) & C_{22}(L) \end{bmatrix} \begin{bmatrix} e_{E,t} \\ e_{FR,t} \end{bmatrix}, \tag{2}$$

where $C(L)$s are polynomials in the lag operator $L; e_E$ and $e_{F,R}$ are the structural shock to the exchange rate and the structural shocks to foreign exchange reserves, respectively; e is a two-by-one vector of structural shocks; $e = (e_E\ e_{FR})$'; var$(e) = \Omega$; and Ω is a diagonal matrix. The sign restrictions imposed on this model are $C_{11}(0) \geq 0, C_{12}(0) \geq 0, C_{21}(0) \leq 0$, and $C_{22}(0) \geq 0$.

To infer the degree of exchange rate stabilization, the dynamic policy reaction function is calculated. This function shows the reaction of the foreign exchange reserves to the exchange rate over time in the presence of shocks to the exchange rate. From equation (2), the impulse responses of the exchange rate and foreign exchange reserves to the shocks to the exchange rate are

$$\Delta E_t(e_E) \equiv C_{11}(L)e_{E,t}, \tag{3}$$

$$\Delta FR_t(e_E) \equiv C_{21}(L)e_{E,t}. \tag{4}$$

That is, $\Delta E_t(e_E)$ and $\Delta FR_t(e_E)$ are the exchange rate and foreign exchange reserve changes in the presence of the shocks to the exchange rate only. By combining (3) and (4),

$$\Delta FR_t(e_E) = \frac{C_{21}(L)}{C_{11}(L)}\Delta E_t(e_E). \tag{5}$$

The coefficients on $\Delta E_t(e_E), \Delta E_{t-1}(e_E), \Delta E_{t-2}(e_E), \ldots$ in equation (5) show how much the percentages of the foreign exchange reserves change over time in reaction to a 1 percent depreciation of the exchange rate in the presence of the shocks to the exchange rate.

In the above, the dynamic policy reaction function is constructed by exploiting the impulse responses to the exchange rate shocks. This

[6] Refer to Canova and De Nicolo (2002) for similar types of sign restrictions.

procedure is essentially equivalent to recovering the policy reaction function after controlling the simultaneity between policy instruments and the exchange rate in this two-variable model as shown below.

The structural-form equations in VAR (vector autoregression) form are

$$\begin{bmatrix} B_{0,11} & B_{0,12} \\ B_{0,21} & B_{0,22} \end{bmatrix} \begin{bmatrix} \Delta E_t \\ \Delta FR_t \end{bmatrix} = \begin{bmatrix} B_{11}(L) & B_{12}(L) \\ B_{21}(L) & B_{22}(L) \end{bmatrix} \begin{bmatrix} \Delta E_{t-1} \\ \Delta FR_{t-1} \end{bmatrix} + \begin{bmatrix} e_{E,t} \\ e_{FR,t} \end{bmatrix}, \tag{6}$$

where B_0s are constants and $B(L)$s are polynomials in the lag operator, L. The structural-form coefficients of the VMA from (2) and the VAR from (6) are related by $C(L) = (B0 - B(L)L) - 1$. Note that the first equation in (6) can be interpreted as the foreign exchange market equation and the second equation as the policy reaction function.[7]

From the second equation in (6),

$$\Delta FR_t = (B_{0,22} - B_{22}(L)L)^{-1} \left[(B_{0,21} - B_{21}(L)L)\, \Delta E_t + e_{FR,t} \right]. \tag{7}$$

By tracing coefficients on $\Delta E_t, \Delta E_{t-1}, \Delta E_{t-2}, \ldots$ in (7), we can examine the percentages' change that the foreign exchange reserves exhibit over time in reaction to a 1 percent depreciation in the exchange rate. In this two-variable model, using the relation $C(L) = (B0 - B(L)L) - 1$, it can be shown that the coefficients in equations (5) and (7) are the same, i.e., $\frac{B_{0,21} - B_{21}(L)L}{B_{0,22} - B_{22}(L)L} = \frac{C_{21}(L)}{C_{11}(L)}$. That is, by exploiting the impulse responses to the shocks to the exchange rate that the policy reacts to, the actual policy reaction function can be recovered.

[7]It can be shown that the sign restrictions on impulse responses also imply corresponding sign restrictions on contemporaneous structural parameters, which are $B_{0,11} \geq 0, B_{0,12} \leq 0, B_{0,21} \geq 0$, and $B_{0,22} \geq 0$. The restrictions on the contemporaneous structural parameters, B_0, can be easily interpreted as follows. An increase in the foreign exchange reserves depreciates the exchange rate (in the foreign exchange market), while the policy authority decreases the foreign exchange reserves in reaction to the exchange rate depreciation in order to stabilize the exchange rate (in the policy reaction function).

To infer the interest rate reactions to the exchange rate, a two-variable model is constructed that includes the log of exchange rate changes and the interest rate changes. For the interest rate, a difference form is used following past studies, although mixed evidence is found on the hypothesis of a unit root in the interest rate. In this model, the restriction is imposed such that a positive shock to the interest rate decreases the exchange rate (since an increase in the interest rate makes the domestic currency asset more attractive) while a positive shock to the exchange rate increases the interest rate (since the policy authority tries to stabilize the exchange rate by increasing the interest rate). That is, in the structural VMA form,

$$\begin{bmatrix} \Delta E_t \\ \Delta R_t \end{bmatrix} = \begin{bmatrix} C_{11}(L) & C_{12}(L) \\ C_{21}(L) & C_{22}(L) \end{bmatrix} \begin{bmatrix} e_{E,t} \\ e_{R,t} \end{bmatrix}, \tag{8}$$

where R is the interest rate; e_E and e_R are the structural shock to the exchange rate and the structural shocks to interest rate, respectively; and the sign restrictions imposed on this model are $C_{11}(0) \geq 0, C_{12}(0) \leq 0, C_{21}(0) \geq 0$, and $C_{22}(0) \geq 0$.

3. Exchange Rate Arrangements

3.1 De Jure Exchange Rate Arrangements

A number of countries have experienced a severe currency crisis in the 1990s and the 2000s. Among these, eleven countries are considered: five Asian crisis countries (Korea, Indonesia, Philippines, Malaysia, and Thailand), Mexico, Brazil, Russia, Ecuador, Bulgaria, and Turkey. Most of these countries announced changes in the exchange rate regime after the crisis. Table 1 reports roughly the date of the currency crisis and de jure exchange rate regime that each country reported to the International Monetary Fund (IMF), found in the IMF's *Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER).*

Eight countries announced a free float (independently floating) within one and a half years of the onset of the crisis. Among these countries, five countries (Korea, Indonesia, Mexico, Brazil, and Russia) changed from a managed float, Thailand changed from a fixed exchange rate regime, Turkey changed from a crawling peg, and

Table 1. De Jure Exchange Rate Regime Classification

Country	Crisis Date	De Jure Exchange Rate Regime Classification
Korea	1997:M9	Mar. 1980–Dec. 15, 1997: Managed Floating Dec. 16, 1997–: Independently Floating
Indonesia	1997:M6	Nov. 1978–Aug. 13, 1997: Managed Floating Aug. 14, 1997–June 29, 2001: Independently Floating June 30, 2001–: Managed Floating
The Philippines	1997:M6	Jan. 1988–: Independently Floating
Malaysia	1997:M6	Mar. 1990–Nov. 1992: Fixed Dec. 1992–Sep. 1, 1998: Managed Floating Sep. 2, 1998–: Fixed
Thailand	1997:M7	Jan. 1970–July 1, 1997: Fixed July 2, 1997–June 29, 2001: Independently Floating June 30, 2001: Managed Floating
Mexico	1994:M11	1982–Dec. 21, 1994: Managed Floating Dec. 22, 1994–: Independently Floating
Brazil	1998:M12	July 1, 1994–Jan. 17, 1999: Managed Floating Jan. 18, 1999: Independently Floating
Russia	1998:M7	July 6, 1995–Sep. 1, 1998: Managed Floating (Band) Sep. 2, 1998–Sep. 29, 1999: Managed Floating Sep. 30, 1999–Nov. 30, 2000: Independently Floating Dec. 1, 2000–: Managed Floating
Ecuador	1999:M12	Oct. 27, 1995–Feb. 11, 1999: Managed Floating (Band) Feb. 12, 1999–Mar. 12, 2000: Independently Floating Mar. 13, 2000–: Dollarization
Bulgaria	1996:M12	Feb. 8, 1991–June 30, 1997: Independently Floating July 1, 1997–Dec. 31, 1998: Fixed (Pegged to DM) Jan. 1, 1999–: Currency Board
Turkey	2001:M1	1975–June 29, 1998: Managed Floating June 30, 1998–Feb. 21, 2001: Crawling Peg Feb. 22, 2001–: Independently Floating

the Philippines continued a free float. In one or two years, Indonesia, Thailand, and Russia made another transition to a managed float. On the other hand, three countries adopted a fixed exchange rate regime within one and a half years after the onset of the crisis. Malaysia changed from a managed float to a peg (with capital account restrictions). Bulgaria changed from a free float to a soft peg, and then announced a hard peg (currency board). Ecuador changed from a managed float/free float to a hard peg (dollarization).

Pre-crisis regimes may be described as intermediate regimes such as a managed float and soft peg. There are eight or nine such cases.[8] On the other hand, post-crisis regimes are directed more toward polar regimes such as a currency board, dollarization, and free float. There are ten such cases, although three of them made another transition from a free float to a managed float within a few years after the crisis. Overall, based on de jure regime classification, the bipolar view has some support.

3.2 Data and Benchmarks

Although some support for the bipolar view was found based on de jure classification, as suggested by Calvo and Reinhart (2002), each country may act differently from what they say. In order to infer de facto exchange rate arrangements in each country, the methodology developed in section 2 is applied in this section.

During the periods around the crisis date, abnormal behaviors of the exchange rate and the policy instruments are often observed. Therefore, some months before and after the crisis dates are excluded for the estimation.[9] Also, in each country, the sample size of the pre-crisis period has been adjusted to be roughly equal to the sample size of the post-crisis period, in order to make a better comparison between the pre- and post-crisis periods. The estimation periods are reported in table 2.

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[8]The case of Ecuador may not be clearly categorized. Ecuador announced a managed float from 1995, but then announced a free float from early 1999. The crisis occurred in late 1999.

[9]In this regard, there are some claims that the effects of monetary policy on the exchange rate are dramatically different during a crisis period. For example, Radelet and Sachs (1998), Stiglitz (1999), and Wade (1998) suggest that a high interest rate policy further depreciated the currency during a currency crisis.

Table 2. Standard Deviations and Correlations of Innovations in Exchange Rate and Policy Instruments

Country vs. Crisis Date	Estimation Period	Model with Reserves			Model with Interest Rate		
		$\sigma(\varepsilon_E)$	$\sigma(\varepsilon_{FR})$	$\rho(\varepsilon_E, \varepsilon_{FR})$	$\sigma(\varepsilon_E)$	$\sigma(\varepsilon_R)$	$\rho(\varepsilon_E, \varepsilon_R)$
Japan ($)	1983:M1–2003:M12	2.70	1.11	−0.35	2.70	0.23	0.10
Australia ($)	1984:M1–2003:M12	2.34	5.40	−0.31	2.34	0.48	0.11
Denmark (DM)	1979:M3–1998:M12	0.66	15.42	−0.17	0.66	1.50	0.10
	1999:M1–2003:M12	0.10	12.21	−0.10	0.10	0.21	0.37
Korea ($)	1992:M1–1996:M12	0.68	2.76	−0.26	0.67	1.22	0.12
1997:M9	1999:M1–2003:M12	1.85	5.72	−0.24	1.86	0.09	−0.17
Indonesia ($)	1992:M1–1996:M12	0.23	3.76	0.16	0.22	1.02	0.13
1997:M6	1999:M1–2001:M6	5.62	6.22	−0.53	5.64	3.49	0.25
	2001:M7–2003:M12	2.82	2.88	−0.25	2.87	1.75	0.14
Philippines ($)	1992:M1–1996:M12	1.33	4.98	−0.12	1.33	3.88	0.09
1997:M6	1999:M1–2003:M12	1.67	5.39	−0.22	1.60	0.55	0.32
Malaysia ($)	1992:M12–1996:M12	1.12	16.24	0.50	1.20	0.28	−0.17
1997:M6	1999:M1–2003:M12	—	—	—	—	—	—
Thailand ($)	1992:M12–1996:M12	0.37	4.13	−0.07	0.36	1.89	−0.14
1997:M7	1999:M1–2001:M6	1.69	4.11	−0.17	1.72	0.37	0.14
	2001:M7–2003:M12	1.11	4.57	−0.36	1.16	0.15	−0.11

(*continued*)

Table 2. (Continued)

Country vs. Crisis Date	Estimation Period	Model with Reserves			Model with Interest Rate		
		$\sigma(\varepsilon_E)$	$\sigma(\varepsilon_{FR})$	$\rho(\varepsilon_E, \varepsilon_{FR})$	$\sigma(\varepsilon_E)$	$\sigma(\varepsilon_R)$	$\rho(\varepsilon_E, \varepsilon_R)$
Mexico ($)	1989:M1–1993:M12	0.52	12.38	−0.33	0.54	2.67	0.07
1994:M11	1997:M1–2003:M12	2.14	4.60	−0.30	2.14	2.40	0.74
Brazil ($)	1994:M7–1997:M12	1.13	5.72	−0.27	1.04	5.23	0.43
1998:M12	2000:M1–2003:M12	4.34	8.13	0.05	4.32	0.49	0.17
Russia ($)	1995:M8–1997:M12	0.33	6.58	−0.00	0.34	24.47	0.18
1998:M7	1999:M10–2000:M11	1.46	3.43	−0.59	1.38	2.46	0.34
	2000:M12–2003:M12	0.47	4.25	−0.32	0.47	4.19	0.23
Ecuador ($)	1995:M11–1998:M12	2.20	11.11	−0.26	2.39	2.33	−0.02
1999:M12	2001:M1–2003:M12	—	—	—	—	—	—
Bulgaria (DM)	1993:M12–1995:M12	5.90	11.66	0.03	5.88	3.41	0.54
1996:M12	1997:M7–1998:M12	0.14	9.27	−0.04	0.14	0.34	0.32
	1999:M1–2003:M12	—	—	—	—	—	—
Turkey (DM)	1993:M7–1998:M6	5.64	10.51	−0.12	4.72	40.37	0.13
2001:M1	1999:M1–2000:M6	1.24	6.34	−0.08	1.43	8.15	−0.03
	2002:M1–2003:M12	4.51	9.98	−0.29	4.43	1.21	0.23

Note: The numbers show the standard deviations (σ's) of and the correlations (ρ's) between the reduced-form residuals.

The benchmarks of free floaters are Japan and Australia. Both countries are generally regarded as free floaters.[10] The other two G3 countries, Germany and the United States, are also regarded as free floaters. However, Germany has not been used as the benchmark since Germany went through important structural changes such as German unification and European monetary unification. On the other hand, it is less clear that the U.S. results are comparable to other countries since official foreign exchange intervention data shows that transactions of both the German mark (or euro) and the Japanese yen are significant portions of total interventions and the U.S. dollar is the foremost reserve currency of the world. In contrast, Japanese foreign exchange intervention data shows that most portions are transactions of U.S. dollars. Therefore, Japan seems to be a better benchmark than the United States and Germany. Estimation periods are from January 1983 to December 2003 for Japan and from January 1984 to December 2003 for Australia, which has been a free floater.[11]

On the other hand, verifying a fixed exchange rate regime from actual data is relatively easy since the exchange rate is mostly fixed in a fixed exchange rate regime. It is, nevertheless, still worthwhile to have the benchmark case of a tightly managed exchange rate (although not literally fixed) in order to have some idea of the reaction size of a tightly managed exchange rate regime, and also in order to check the validity of the current methodology. Denmark is used as the benchmark. Since 1979, Denmark participated in the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS). Since 1998, the Danish krone has been pegged to the euro within an official band of +/–2.25 percentage points. The ERM period can

[10]The exchange rate stabilizing actions of Japan might not be directly comparable to those of the countries in the sample. Japan's currency is a reserve currency of some countries. Japan is difficult to regard as a small, open economy that characterizes the countries in the sample. Therefore, another benchmark country, Australia, is considered.

[11]The estimation dates are chosen based on the IMF's *AREAEAR*. To be more consistent with the estimation periods of the sample countries, the benchmark cases were also estimated over the periods 1992–96 and 1999–2003. The main conclusions do not change when the estimates for those periods are used. In addition, the same estimation period is used for both the benchmark case and the crisis country for the probability measure reported in table 3. This measure will be explained later.

be regarded as the case in which the exchange rate arrangement is somewhat less flexible than the usual managed float (with discretion) while the latter period acts as the case for fixed exchange rate arrangements within a narrow band. An ERM country has been chosen, since the ERM is a good example of tightly managed exchange rate arrangements. Among ERM countries, Denmark is chosen, as it is one of very few countries that have been within the ERM without much trouble.[12] Estimation periods for Denmark are from March 1979 to December 1998 and from January 1999 to December 2003.

Monthly data have been used for the estimation. All data series are collected from the IMF's International Financial Statistics. For European countries, the exchange rate against the Deutsch mark (DM), before 1999, or the euro, from 1999, has been used. For all other countries, the exchange rate against the U.S. dollar is used.[13] The foreign exchange reserves, in terms of foreign currency, have been used (that is, the foreign exchange reserves in terms of the DM or the euro for European countries and the foreign exchange reserves in terms of U.S. dollars for other countries) because the exchange rate movements would change foreign exchange reserves in terms of the domestic currency without any foreign exchange policy actions.[14] The original monetary base data is in terms of domestic currency, so it is converted to foreign currency terms.[15] For the interest rate, money-market rates have been used.[16] In all estimations, one lag has been chosen based on the Schwarz criterion and a constant term has been included.

3.3 Volatility and Co-movements of Policy Instruments and Exchange Rate

I present the information from the variance-covariance matrix of reduced-form residuals (Σ), to infer whether the overall behaviors of policy instruments and the exchange rate in the post-crisis period differ from those in the pre-crisis period. Table 2 reports the standard

[12]See Eichengreen and Wyplosz (1993).
[13]Monthly end-of-period bilateral exchange rates (IFS line ..AE.) are used.
[14]For reserves, total reserves minus gold (IFS line .1L.D) are used.
[15]For monetary base, IFS line 14... is used.
[16]IFS line 60B.. is used, except for Ecuador. For Ecuador, discount rate (IFS line 60...) is used.

deviations of the innovations in policy instruments' changes and the exchange rate changes (ε_{FR} and ε_E in the first model and ε_R and ε_E in the second model) and the correlation between those two variables for each country during the pre-crisis and the post-crisis periods. The first column shows the country name, the base foreign currency (in parentheses, "DM" indicates German mark or euro), and the crisis date (below the country name). The second column shows the estimation period; the third, fourth, and fifth columns represent, respectively, the standard deviations of ε_E and ε_{FR}, and the correlation between ε_E and ε_{FR}, in the model with foreign exchange reserves; the sixth, seventh, and eighth columns show the standard deviations of ε_E and ε_R, and the correlation between ε_E and ε_R, respectively, in the model with the interest rate.

The standard deviation of innovations in exchange rate changes is higher but the standard deviations of innovations in the two policy instruments are lower in Japan and Australia than in Denmark. This result is in fact not surprising. In a tightly managed exchange rate regime, the policy authority adjusts its policy instruments to a great extent to stabilize the exchange rate, leading to a high level of volatilities in the changes of the policy instruments but a low level of volatility in exchange rate changes.

In most crisis countries, the volatilities of policy instruments' changes and the exchange rate changes in the pre-crisis period are substantially different from those in the post-crisis period. The observation indicates that the exchange rate regime is likely to have changed after the crisis. For many countries, the standard deviation of the innovations in exchange rate changes is higher but the standard deviations of the innovations in two policy instruments' changes are lower in the post-crisis period compared with the pre-crisis period. The difference in the level of standard deviations may imply a transition toward a more flexible exchange rate regime. On the other hand, there are some cases in which the standard deviations of both the exchange rate changes and policy instruments' changes rise (or fall), based on which it is not so easy to draw a clear conclusion on how the exchange rate regime has changed. A more clear inference can be made based on the estimated policy reaction function from the structural VAR model in the next section.

In most cases, the correlation between the exchange rate changes and foreign exchange reserve changes is relatively small in its absolute value; there are only five cases (out of fifty-six) in which the correlation is larger than 0.37. Because exchange rate shocks and policy instrument shocks result in the opposite signs for the correlation between the changes in the exchange rate and policy instruments, a weak overall or unconditional correlation may suggest that neither exchange rate shocks nor policy instrument shocks are dominant. This, in turn, may suggest that the structural VAR modeling (identifying two shocks separately) is a worthwhile attempt. Albeit small, the correlation between the exchange rate changes and foreign exchange changes is often negative and the correlation between the exchange rate changes and the interest rate changes is often positive. This may suggest that the stabilizing actions of policy instruments (in response to exchange rate shocks) are stronger than policy instrument shocks (that affect exchange rate). In the next section, I present the results from the structural VAR model that separates the two types of shocks.

3.4 Estimated Reaction Functions, Probability Measures, and Impulse Responses

The estimated reaction function from the structural VAR model is reported in table 3. The first column shows the country name and the base foreign currency. The second column shows the estimation period; the third, the de jure classification reported to the IMF; the fourth and fifth, the reaction function of the foreign exchange reserves to the exchange rate (the first month and the sixth month); and the sixth and seventh, the reaction function of the interest rate. Note that all the numbers of the reaction functions are cumulative numbers over time. The numbers in parentheses are 68 percent probability bands. There are three cases in which the numbers are not reported because the exchange rate is literally fixed and the reaction functions cannot be calculated.

The estimated reaction function with probability bands provides important information on the size of policy reactions, but it is not easy to clearly infer whether the size of the policy reactions of each country is significantly different from the benchmark cases. However, a clear inference on such issues is important. As an example, in order to investigate the case of “fear of floating,” it needs to be tested whether the size of the policy reactions of a country that claims a

Table 3. Estimated Policy Reaction Function

Country vs. Crisis Date	Estimation Period	De Jure	Reserve Reactions		Interest Rate Reactions	
			One Month	Six Month	One Month	Six Month
Japan ($)	1983:M1–2003:M12	IF	−0.33 (−0.10,−0.71)	−0.30 (−0.11,−0.63)	0.08 (0.02,0.24)	0.06 (0.02,0.19)
Australia ($)	1984:M1–2003:M12	IF	−1.84 (−0.60,−4.13)	−1.64 (−0.72,−3.17)	0.18 (0.05,0.54)	0.29 (0.10,0.95)
Denmark (DM)	1979:M3–1998:M12	EM	−20.5 (−5.75,−57.3)	−17.6 (−7.48,−51.7)	2.13 (0.59,6.60)	1.32 (0.38,3.79)
	1999:M1–2003:M12	F	−113.4 (−33.3,−356)	−121.0 (−40.1,−274)	1.59 (0.52,3.43)	2.69 (0.70,5.82)
Korea ($)	1992:M1–1996:M12	MF	−3.35 (−0.98,−7.92)	−2.92 (−1.37,−6.62)	1.64 (0.48,4.89)	0.71 (0.05,1.54)
1997:M9	1999:M1–2003:M12	IF	−2.55 (−0.79,−6.27)	−3.33 (−1.83,−6.23)	0.06 (0.01,0.34)	0.09 (0.01,0.56)
Indonesia ($)	1992:M1–1996:M12	MF	−19.6 (−4.54,−104.5)	−23.0 (−5.09,−991)	3.99 (1.14,11.8)	3.61 (1.05,22.5)
1997:M6	1999:M1–2001:M6	IF	−0.80 (−0.29,−1.51)	−0.38 (−0.05,−0.79)	0.52 (0.16,1.31)	0.56 (0.27,1.18)
	2001:M7–2003:M12	MF	−0.84 (−0.25,−2.07)	−0.91 (−0.43,−1.60)	0.55 (0.15,1.63)	0.18 (−0.03,0.55)
Philippines ($)	1992:M1–1996:M12	IF	−3.26 (−0.89,−9.91)	−2.92 (−1.11,−7.46)	2.75 (0.71,8.74)	1.12 (0.38,3.51)
1997:M6	1999:M1–2003:M12	IF	−2.68 (−0.80,−6.79)	−2.34 (−0.81,−5.38)	0.28 (0.09,0.62)	0.35 (0.13,0.58)
Malaysia ($)	1992:M12–1996:M12	MF	−21.39 (−4.98,−93.6)	−74.48 (−9.1,−3140)	0.30 (0.06,1.54)	0.21 (0.04,1.15)
1997:M6	1999:M1–2003:M12	F	—	—	—	—
Thailand ($)	1992:M12–1996:M12	F	−10.23 (−2.79,−34.8)	−10.02 (−4.53,−26.9)	5.98 (1.41,30.17)	7.75 (2.70,273)
1997:M7	1999:M1–2001:M6	IF	−2.10 (−0.60,−5.86)	−0.93 (0.07,−2.15)	0.19 (0.05,0.55)	0.10 (0.00,0.42)
	2001:M7–2003:M12	MF	−3.20 (−1.00,−6.97)	−2.83 (−1.13,−4.58)	0.14 (0.03,0.66)	0.02 (−1.02,0.11)

(*continued*)

Table 3. (Continued)

Country vs. Crisis Date	Estimation Period	De Jure	Reserve Reactions		Interest Rate Reactions	
			One Month	Six Month	One Month	Six Month
Mexico ($)	1989:M1–1993:M12	MF	−19.12 (−6.32,−42.0)	−5.95 (−1.09,−18.46)	4.69 (1.26,15.5)	2.80 (0.25,13.09)
1994:M11	1997:M1–2003:M12	IF	−1.71 (−0.53,−4.01)	−0.96 (−0.09,−2.55)	0.84 (0.42,1.25)	0.84 (0.50,1.18)
Brazil ($)	1994:M7–1997:M12	MF	−4.09 (−1.26,−9.98)	−2.82 (0.26,−12.08)	3.86 (1.35,7.72)	2.23 (0.26,4.32)
1998:M12	2000:M1–2003:M12	IF	−1.95 (−0.49,−7.95)	−0.85 (−0.05,−4.18)	0.10 (0.03,0.27)	0.38 (0.16,1.06)
Russia ($)	1995:M8–1997:M12	MF	−19.1 (−5.16,−72.0)	−1.92 (48.1,−6.09)	60.0 (17.6,165.4)	5.85 (−6.26,25.9)
1998:M7	1999:M10–2000:M11	IF	−1.75 (−0.71,−3.13)	−1.17 (0.23,−2.73)	1.40 (0.46,3.27)	0.32 (−0.28,2.28)
	2000:M12–2003:M12	MF	−7.26 (−2.27,−16.6)	−4.44 (−2.56,−6.84)	7.25 (2.18,18.66)	1.59 (0.36,4.24)
Ecuador ($)	1995:M11–1998:M12	MF	−4.12 (−1.23,−9.78)	−1.43 (0.97,−3.26)	1.03 (0.26,4.15)	1.23 (0.38,3.29)
1999:M12	2001:M1–2003:M12	F(D)	—	—	—	—
Bulgaria (DM)	1993:M12–1995:M12	IF	−2.02 (−0.51,−7.88)	0.21 (1.23,−1.46)	0.43 (0.16,0.81)	0.47 (0.05,0.91)
1996:M12	1997:M7–1998:M12	F	−62.5 (−16.8,−217.2)	−84.3 (−23.5,−299.0)	1.95 (0.63,4.59)	3.32 (1.20,8.85)
	1999:M1–2003:M12	F(C)	—	—	—	—
Turkey (DM)	1993:M7–1998:M6	MF	−1.75 (−0.47,−5.20)	−1.30 (−0.44,−2.48)	7.53 (2.12,22.11)	1.09 (−296.7,2.96)
2001:M1	1999:M1–2000:M6	CD	−4.68 (−1.31,−16.0)	−5.93 (−1.95,−491.7)	5.86 (1.48,23.80)	−1.47 (−504,1.47)
	2002:M1–2003:M12	IF	−1.78 (−0.53,−4.27)	−1.15 (−0.40,−3.05)	0.23 (0.07,0.57)	0.41 (0.19,1.61)

Notes: IF: Independently Floating, MF: Managed Floating, F: Fixed, CP: Crawling Peg, F(D): Dollarization, F(C): Currency Board, EM: Exchange Rate Mechanism. The numbers show the cumulative policy reaction functions, and the numbers in parentheses show 68 percent probability bands.

free float is stronger than those of the benchmark free floaters. In this regard, the probability that the policy reaction of each country is weaker or stronger than the benchmark cases is formally calculated using simulation experiments.[17]

In table 4, each number under the benchmark cases of free floating ("Japan (IF)" and "Australia (IF)") shows the probability that the reaction of each country is not stronger than that of the benchmark case. These numbers can be regarded as the statistics for the test of the null hypothesis that each country actually adopted a free float. A low probability indicates a rejection of the null hypothesis at the probability level. This rejection may suggest that the country is not a free floater and controls the exchange rate more tightly than a free floater. On the other hand, each number under the benchmark cases of the tightly controlled exchange rate arrangements ("Denmark (EM)" and "Denmark (F)") shows the probability that the reactions of each country are not weaker than those of the benchmark cases. These numbers can be regarded as statistics for the test of the null hypothesis that each country adopted a very tightly managed exchange rate policy. Again, a low probability may indicate a rejection of the null hypothesis. This rejection suggests that the exchange rate control is weaker than very tightly managed exchange rate arrangements.

In table 4, the probabilities that are not larger than 0.05 and 0.1 are denoted as underlined bold and bold characters, respectively. To control the time factor that may affect the exchange rate and policy instrument volatility for all countries, the longest sample period that can be applied to both the benchmark case and the country under consideration has been used. For example, to evaluate the post-crisis period of Korea (1999–2003), the benchmark cases are also estimated for the period 1999–2003.[18]

Finally, the estimated impulse responses in percentage terms, with 68 percent probability bands, in the two-variable model with the exchange rate and foreign exchange reserves for the post-crisis

[17]See the appendix for more details.

[18]Since the sample period of the Denmark (EM) case does not have any overlap with the post-crisis period of Korea, the original period of the Denmark (EM) case, March 1979–December 1998, has been used. In general, the original period of the benchmark case is used when there is no overlap between the periods of the benchmark case and each case in question.

Table 4. Probability Measures

Country	Estimation Period	Japan (IF)				Australia (IF)				Denmark (EM)				Denmark (F)			
		Reserve		Int Rate		Reserve		Int Rate		Reserve		Int Rate		Reserve		Int Rate	
		1m	6m	1m	6m	1m	6m	1m	6m	1m	6m	1m	6m	1m	6m	1m	6m
Japan	1983:M1–2003:M12	—	—	—	—	—	—	—	—	**.00**	**.00**	**.06**	.13	**.00**	**.06**	**.03**	.12
Australia	1984:M1–2003:M12	.11	**.07**	.30	.15	—	—	—	—	**.05**	**.01**	.15	.37	**.01**	**.06**	**.07**	**.07**
Denmark	1979:M3–1998:M12	**.00**	**.00**	**.06**	.13	**.05**	**.01**	.15	.37	—	—	—	—	.15	.15	.60	.36
	1999:M1–2003:M12	**.00**	**.06**	**.03**	.12	**.01**	**.06**	**.07**	**.07**	—	—	—	—	—	—	—	—
Korea	1992:M1–1996:M12	**.05**	**.02**	**.05**	.20	.46	.46	.15	.39	.18	.12	.56	.50	**.02**	**.07**	.52	.19
1997:M9	1999:M1–2003:M12	.11	**.02**	.30	.34	.45	.21	.50	.30	**.10**	**.06**	**.07**	.15	**.02**	**.07**	**.08**	.15
Indonesia	1992:M1–1996:M12	**.01**	**.03**	**.02**	**.05**	.15	.21	**.08**	.18	.57	.60	.76	.86	.21	.33	.75	.61
1997:M6	1999:M1–2001:M6	.31	.56	**.08**	.15	.81	.66	.13	**.07**	**.03**	**.00**	.19	.29	**.01**	**.04**	.19	.22
	2001:M7–2003:M12	.35	.24	**.01**	.23	.73	.88	.16	.37	**.04**	**.01**	.22	.14	**.01**	.18	.31	.11
Philippines	1992:M1–1996:M12	**.06**	**.05**	**.04**	**.10**	.45	.48	**.10**	.28	.20	.14	.68	.66	**.04**	**.08**	.65	.33
1997:M6	1999:M1–2003:M12	.11	.11	.11	.17	.43	.37	.26	.13	.11	**.05**	**.10**	.15	**.02**	**.07**	.12	.11
Malaysia	1992:M12–1996:M12	**.01**	**.01**	.18	.30	.21	.25	.38	.52	.65	.77	.25	.39	.21	.50	.21	.18
1997:M6	1999:M1–2003:M12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Thailand	1992:M12–1996:M12	**.02**	**.03**	**.01**	**.04**	.29	.38	**.06**	**.09**	.48	.48	.82	.97	.11	.12	.80	.80
1997:M7	1999:M1–2001:M6	.14	.36	.18	.37	.55	.52	.28	.32	**.10**	**.01**	**.09**	.13	**.03**	**.05**	**.08**	.18
	2001:M7–2003:M12	**.10**	.11	**.04**	.41	.36	.48	.34	.62	.11	**.02**	.11	**.05**	**.02**	.18	.15	**.06**

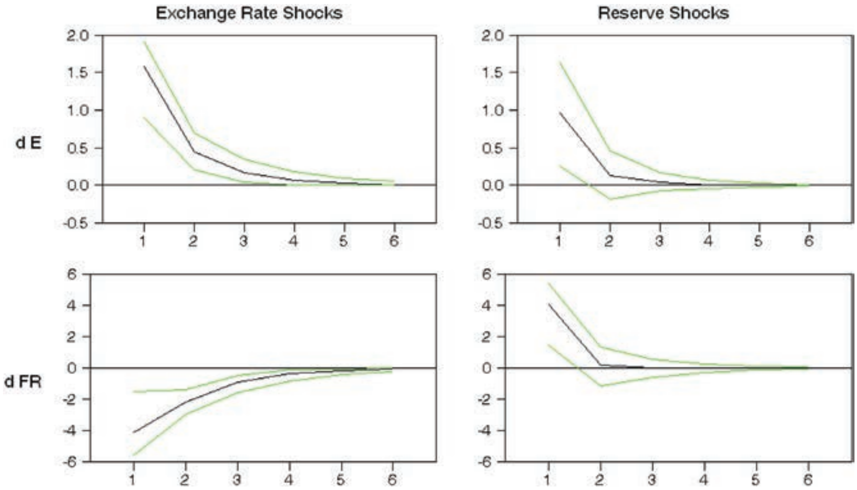
(continued)

Table 4. (Continued)

Country	Estimation Period	Japan (IF)				Australia (IF)				Denmark (EM)				Denmark (F)			
		Reserve		Int Rate		Reserve		Int Rate		Reserve		Int Rate		Reserve		Int Rate	
		1m	6m	1m	6m	1m	6m	1m	6m	1m	6m	1m	6m	1m	6m	1m	6m
Mexico	1989:M1–1993:M12	**.01**	.11	**.02**	.15	**.06**	.29	**.06**	.19	.50	.22	.76	.78	.12	**.09**	.77	.52
1994:M11	1997:M1–2003:M12	.15	.31	**.02**	**.03**	.55	.61	**.08**	**.06**	**.07**	**.01**	.22	.33	**.01**	**.06**	.27	.19
Brazil	1994:M7–1997:M12	**.04**	.21	**.01**	.20	.46	.51	**.08**	.25	.24	.20	.92	.54	**.03**	**.09**	.75	.42
1998:M12	2000:M1–2003:M12	.17	.39	.22	.14	.48	.58	.46	**.09**	.13	**.08**	**.05**	.24	**.04**	.11	**.05**	.17
Russia	1995:M8–1997:M12	**.01**	.35	**.00**	.32	.19	.58	**.00**	.35	.42	**.05**	.99	.65	.18	**.07**	.98	.58
1998:M7	1999:M10–2000:M11	.13	.48	**.03**	.43	.67	.44	**.02**	.33	**.06**	**.02**	.39	.28	**.02**	**.10**	.29	.14
	2000:M12–2003:M12	**.04**	**.04**	**.01**	.17	.15	.13	**.02**	.16	.24	**.07**	.76	.53	**.05**	.12	.83	.51
Ecuador	1995:M11–1998:M12	**.05**	.28	**.01**	**.08**	.39	.55	**.09**	.18	**.07**	**.06**	.51	.49	**.04**	**.06**	.42	.33
1999:M12	2001:M1–2003:M12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bulgaria	1993:M12–1995:M12	**.10**	.62	**.10**	.34	.53	.82	.40	.30	.29	**.08**	.30	.18	**.03**	**.06**	.15	.14
1996:M12	1997:M7–1998:M12	**.01**	**.08**	**.00**	**.02**	**.05**	**.09**	**.01**	**.05**	.76	.79	.47	.72	.35	.61	.42	.32
	1999:M1–2003:M12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Turkey	1993:M7–1998:M6	.12	.13	**.01**	.43	.58	.53	**.03**	.48	.14	**.06**	.96	.58	**.02**	**.06**	.85	.25
2001:M1	1999:M1–2000:M6	**.09**	**.09**	**.01**	.70	.40	.30	**.01**	.68	.22	.34	.72	.17	**.07**	.22	.61	.30
	2002:M1–2003:M12	.21	.27	**.03**	**.09**	.57	.76	.25	**.05**	**.08**	**.04**	**.10**	.28	**.01**	.22	.20	.32

Note: The numbers show the probability that the absolute value of the estimated coefficient is not larger than that of the flexible exchange benchmark cases ("Japan (IF)" and "Australia (IF)") and the probability that the absolute value is not smaller than that of the fixed exchange rate benchmark cases ("Denmark (EM)" and "Denmark (F)").

Figure 1. Impulse Responses, Korea, 1999–2003



period of South Korea, are reported in figure 1. Since the impulse responses themselves do not help much to infer the exact size of policy reaction clearly, only one case is reported. The graphs in the first and the second columns show the responses of percentage changes in the exchange rate and the changes in the foreign exchange reserves (as a percentage of the monetary base in the previous period) to the exchange rate shocks and foreign exchange reserve shocks, respectively. To be consistent with the sign restrictions, the foreign exchange reserves and the exchange rate move in opposite directions in response to exchange rate shocks, while two variables move in the same direction in response to foreign exchange reserve shocks. Note that foreign exchange reserve shocks generate a substantial volatility of exchange rate and foreign exchange reserve movements. Note also that different ratios of exchange rate movements to foreign exchange reserve movements are generated from exchange rate shocks and foreign exchange reserve shocks. These results suggest that the current empirical methodology based on only exchange rate shocks may provide different results than the previous methodology based on unconditional volatility.

3.5 Results for Benchmark Cases

First, the benchmark countries are examined. The point estimates of Japan's foreign exchange reserve reactions show that foreign exchange reserves decreased by 0.33 percent (of the monetary base) in the first month and by 0.30 percent up to the sixth month, as a reaction to a 1 percent exchange rate depreciation. The point estimates of interest rate reactions show that the interest rate increased by 0.06–0.08 percent in reaction to a 1 percent exchange rate depreciation. In Australia, the point estimates of foreign exchange reserve reactions were –1.84 to –1.64 percent while the point estimates of interest rate reactions were 0.18 to 0.29 percent. The point estimates show that exchange rate stabilization was stronger in Australia than in Japan. However, considering wide probability bands, the difference between the two countries does not seem to be statistically significant. To be consistent with this conjecture, the hypothesis that Australian reactions were not stronger than Japanese reactions is not rejected at the 5 percent level in any cases, and is rejected at the 10 percent level in only one out of four cases in table 4.

On the other hand, the estimated reaction function of Denmark implies strong exchange rate stabilization. During the ERM period, foreign exchange reserve reactions were –20.5 to –17.6 percent and interest rate reactions were 2.13 to 1.32 percent. During the post-ERM period, the foreign exchange reserve reactions were even stronger, ranging from –113.4 to –121.0 percent. Interest rate reactions were 1.59 to 2.69 percent. In most cases, the lower band of the Danish reaction (in absolute value) was larger than the upper band of the Australian and Japanese reaction (in absolute value). This implies that the Danish reaction was significantly stronger than the Australian and Japanese reaction. To be consistent, the hypothesis that Japanese and Australian reactions were not weaker than the Danish reactions is frequently rejected at the 5 percent level and mostly rejected at the 10 percent level in table 4. On the other hand, the hypothesis that Danish reactions, during the ERM period, were not weaker than those during the fixed exchange rate period is not rejected at the 10 percent level in any cases.

Overall, the size of the reactions, based on the current methodology, well describes the relative degree of the exchange rate stabilization between a free float and tight exchange rate arrangements such as the ERM and a peg. In addition, the hypothesis test, based on probability measures, can clearly distinguish between a free float and a very tightly managed exchange rate policy.

3.6 Do Crisis Countries Move to Polar Regimes?

Now the main issue of the paper is discussed: Do crisis countries move to polar regimes? To address this question, it is analyzed whether crisis countries adopted free floats by investigating whether the estimated reactions of crisis countries were stronger than those of benchmark free floaters. To answer this question, it would have been enough to identify the number of countries that adopted polar regimes and intermediate regimes since the case of hard pegs can be easily identified.

First, the pre-crisis period was examined. In six countries (Indonesia, Thailand, Mexico, Brazil, Russia, and Ecuador), both reserve reactions and interest rate reactions were far stronger than those of Australia and Japan. In addition, interest rate reactions of three countries (Korea, Malaysia, and Turkey) and reserve reactions of one country (Malaysia) were far stronger than those of Australia and Japan. The only country that did not have far stronger policy reactions was Bulgaria.

This result can be further confirmed by using the probability measures. When Japan was used as the benchmark case, the hypothesis of free floating was rejected at the 5 percent level frequently in all countries but Bulgaria (out of four cases, three for Korea; two for Ecuador, Mexico, Malaysia, the Philippines, Brazil, and Russia; one for Turkey; and all cases for Indonesia and Thailand). Even when Australia was used as the benchmark case, the hypothesis of free floating was rejected in many countries (at the 10 percent level, one case for Indonesia, the Philippines, Brazil, Russia, Ecuador, and Turkey; two cases for Thailand and Mexico). In Bulgaria, it was not rejected when Australia was used as the benchmark. It was rejected only at the 10 percent level (for two out of four cases) when Japan was used as the benchmark.

Therefore, the exchange rate regime in the pre-crisis period can be characterized as intermediate regimes in most countries (ten out of eleven countries) because a free float was rejected and none of these countries adopted a hard peg.

Next, the post-crisis period was analyzed. The estimated policy reactions of the eight countries that announced a free float tended to be similar to or only slightly stronger than those of Australia, although somewhat stronger than those of Japan in many cases. Exceptions were Mexico and Russia; both interest rate and reserve reactions of Russia and interest rate reactions of Mexico were stronger than those of Australia and Japan.

Based on the probability measures, for five countries (four Asian countries and Brazil) among eight de jure free floaters, it is difficult to reject the null hypothesis of free float. The null hypothesis of free float is not rejected in any cases at the 5 percent level for these countries, except for one case of Korea. Even at the 10 percent level, the null hypothesis of free float was rejected in one out of eight cases for Korea and Brazil, two out of sixteen cases for Thailand, three out of sixteen cases for Indonesia, and none of the eight cases for the Philippines.

On the other hand, more frequent rejections were found in Mexico, Russia, and Turkey. For Mexico, it was rejected in two cases at the 5 percent level and four out of eight cases at the 10 percent level. For the de jure managed floating (2000:M12–2003:M12) period of Russia, it was rejected in four out of eight cases at the 5 percent level. For the de jure free-floating (2002:M1–2003:M12) period of Turkey, it was rejected in two and three out of eight cases at the 5 percent and 10 percent level, respectively.

The remaining three countries (Ecuador, Bulgaria, and Malaysia) clearly adopted the fixed exchange rate regime in the post-crisis period, and among them, two countries (Bulgaria and Ecuador) are clearly hard pegs. Overall, at least five countries adopted free float and two countries adopted hard pegs in the post-crisis period. Therefore, at least seven out of eleven countries adopted polar regimes in the post-crisis period.

To summarize, while about ten countries (out of eleven) adopted intermediate regimes during the pre-crisis period, at least seven countries (out of eleven) adopted polar regimes in the post-crisis period, which is summarized in table 5. This result supports the bipolar view, or “hollow middle” hypothesis.

Table 5. De Facto Exchange Rate Regime Classification

Country	Pre-Crisis	Post-Crisis
Korea	INT	IF
Indonesia	INT	IF
The Philippines	INT	IF
Malaysia	INT	INT
Thailand	INT	IF
Mexico	INT	INT
Brazil	INT	IF
Russia	INT	INT
Ecuador	INT	HP
Bulgaria	IF	HP
Turkey	INT	INT

Note: IF: Independently Floating, INT: Intermediate Regime, HP: Hard Peg.

3.7 Do Countries Overstate Exchange Rate Flexibility?

Next we investigated if countries overstate their exchange rate flexibility or understate their exchange rate controls. In order to identify the case of "fear of floating," the policy reactions of crisis countries were compared with the benchmark cases of free floats. In addition to the case of "fear of floating," we also identified if a country claimed a managed float but actually acted more closely to a peg by comparing the policy reactions of crisis countries with the benchmark cases of very tightly managed exchange rate regimes.

In the pre-crisis period, only two countries claimed a free float and eight countries claimed a managed float. In one of two countries that claimed a free float, the Philippines, the interest rate reactions were too large to be regarded as a free float like Australia. In four out of eight countries that claimed a managed float (Russia, Mexico, Malaysia, and Indonesia), the size of reactions was also as strong as the size of the reactions of Denmark during the ERM period. This suggested that these countries managed the exchange rate very tightly.

A similar conclusion can be derived based on the probability measures. In the case of the Philippines, the null hypothesis of a free float was rejected in three and five cases out of eight cases at the 5 percent and the 10 percent level, respectively. For Malaysia and Indonesia, the null hypothesis of a tightly managed exchange rate regime was not rejected in any cases at the 10 percent level. For Mexico, it was rejected in only one out of eight cases at the 10 percent level and in no cases at the 5 percent level. For Russia, it was rejected in one and two out of eight cases at the 5 percent and the 10 percent level, respectively. Overall, about half of the countries that announced a free float or a managed float tended to overstate their exchange rate flexibility.

In the post-crisis period, there were at best three cases of "fear of floating" (Mexico, Turkey, and Russia) out of eight cases that claimed a free float as discussed in the previous section. Further, among three cases that announced a managed float, at least two countries did not seem to overstate their exchange rate flexibility. The hypothesis of a tightly managed exchange rate regime was rejected in three out of eight cases at the 5 percent level for Indonesia and Thailand. For the remaining one case (Russia), it was more difficult to reject the hypothesis. The hypothesis was rejected in one and two out of eight cases at the 5 percent and the 10 percent level, respectively. Overall, four out of eleven cases tend to understate exchange rate flexibility.

To summarize, the cases in which countries overstate the exchange rate flexibility, including "fear of floating," have frequently been found in the samples under consideration. Such a tendency is weaker in the post-crisis period than in the pre-crisis period.

4. Extended Experiments

4.1 Robustness

First, the baseline models include only two variables and two structural shocks; however, the changes in policy instruments and the exchange rate can be driven by the third variable or the additional shock. In this regard, the baseline model is extended to include an additional variable. For the third variable, I consider the industrial production index that contains the information on the overall production activities. I also consider the world commodity price index that captures the information on inflationary pressure and world economic condition.[19] The same four sign restrictions are imposed, but no additional restriction in relation to the third variable is imposed.

Second, the three-variable model is constructed that includes two policy instruments' changes and the exchange rate changes simultaneously. Seven sign restrictions are imposed. Foreign exchange reserve shocks increase (or decrease) the foreign exchange rate reserve changes and decrease (or increase) the exchange rate. Interest rate shocks increase (or decrease) both the interest rate changes and the exchange rate. Exchange rate shocks increase (or decrease) the exchange rate changes and foreign exchange reserve changes but decrease (or increase) the interest rate changes.

The estimated policy reaction functions for the one-month horizon for these three-variable models are reported in table 6. "Base," "IP," "CMP," and "2P" indicate the baseline two-variable model, the three-variable model with industrial production, the three-variable model with world commodity price, and the three-variable model with the two policy instruments simultaneously. In most cases, the estimated policy reaction for each country is slightly stronger in three-variable models with industrial production or world commodity price than in the baseline model. By including an additional variable or shock, the exchange rate shock that policy reacts to is likely to be identified in a narrower sense. Using such shocks, the estimated policy reaction is likely to be stronger. Further, the estimated policy reaction is even stronger in the model with the two policy instruments than in the models with an additional variable. In this model, the exchange rate shocks are identified in a much narrower sense, since the shock is restricted to the one which both of the policy instruments reacts to.

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[19]The industrial production index and the world commodity price index are obtained from International Financial Statistics. Monthly data on industrial production are not available for some countries. The overall world commodity price index is available only from 1992. When the estimation periods include the periods before 1992, non-fuel world commodity price index that is available for the period before 1992 is used.

See Kim (1999) for documentation that the world commodity price is a useful variable containing inflationary pressure when identifying monetary policy shocks for various countries.

Table 6. Estimated Policy Reaction Function from Three-Variable Models (one-month horizon)

Country vs. Crisis Date	Estimation Period	Reserve Reactions				Interest Rate Reactions			
		Base	IP	CMP	2P	Base	IP	CMP	2P
Japan ($)	1983:M1–2003:M12	−0.33	−0.41	−0.44	−0.66	0.08	0.08	0.09	0.18
Australia ($)	1984:M1–2003:M12	−1.84	—	−2.25	−4.04	0.18	—	0.20	0.42
Denmark (DM)	1979:M3–1998:M12	−20.5	−24.0	−26.0	−38.0	2.13	2.23	2.15	4.39
	1999:M1–2003:M12	−113.4	−127.7	−121.1	−169.1	1.59	2.11	2.02	4.01
Korea ($)	1992:M1–1996:M12	−3.35	−4.17	−4.06	−6.57	1.64	1.84	1.81	3.91
1997:M9	1999:M1–2003:M12	−2.55	−3.13	−2.95	−5.52	0.06	0.05	0.05	0.09
Indonesia ($)	1992:M1–1996:M12	−19.6	—	−17.2	−22.7	3.99	—	4.12	11.2
1997:M6	1999:M1–2001:M6	−0.80	−1.10	−1.12	−1.58	0.52	0.62	0.63	0.97
	2001:M7–2003:M12	−0.84	−1.01	−1.04	−1.79	0.55	0.60	0.62	1.24
Philippines ($)	1992:M1–1996:M12	−3.26	−3.72	−3.80	−6.42	2.75	3.00	2.87	6.33
1997:M6	1999:M1–2003:M12	−2.68	−3.22	−3.18	−4.89	0.28	0.36	0.33	0.64
Malaysia ($)	1992:M12–1996:M12	−21.4	−14.2	−14.7	−11.3	0.30	0.22	0.24	0.63
1997:M6	1999:M1–2003:M12	—	—	—	—	—	—	—	—
Thailand ($)	1992:M12–1996:M12	−10.2	—	−11.5	−21.4	5.98	—	5.28	7.20
1997:M7	1999:M1–2001:M6	−2.10	—	−2.42	−2.76	0.19	—	0.21	0.46
	2001:M7–2003:M12	−3.20	—	−4.14	−7.57	0.14	—	0.14	0.22

(*continued*)

Table 6. (Continued)

Country vs. Crisis Date	Estimation Period	Reserve Reactions				Interest Rate Reactions			
		Base	IP	CMP	2P	Base	IP	CMP	2P
Mexico ($)	1989:M1–1993:M12	−19.1	−24.8	−23.8	−45.2	4.69	4.99	4.85	10.7
1994:M11	1997:M1–2003:M12	−1.71	−2.24	−2.07	−1.49	0.84	1.25	1.11	1.52
Brazil ($)	1994:M7–1997:M12	−4.09	−5.31	−4.84	−9.52	3.86	4.82	4.85	7.12
1998:M12	2000:M1–2003:M12	−1.95	−1.81	−1.87	−2.85	0.10	0.11	0.12	0.24
Russia ($)	1995:M8–1997:M12	−19.1	−18.2	−19.3	−28.2	60.0	67.5	68.1	94.2
1998:M7	1999:M10–2000:M11	−1.75	−3.16	−2.35	−3.10	1.40	2.40	1.61	2.76
	2000:M12–2003:M12	−7.26	−9.37	−8.74	−13.8	7.25	8.96	8.97	18.1
Ecuador ($)	1995:M11–1998:M12	−4.12	—	−5.05	−8.21	1.03	—	0.96	2.19
1999:M12	2001:M1–2003:M12	—	—	—	—	—	—	—	—
Bulgaria (DM)	1993:M12–1995:M12	−2.02	—	−1.92	−2.91	0.43	—	0.61	0.93
1996:M12	1997:M7–1998:M12	−62.5	—	−82.1	−93.7	1.95	—	3.00	4.11
	1999:M1–2003:M12	—	—	—	—	—	—	—	—
Turkey (DM)	1993:M7–1998:M6	−1.75	−1.82	−1.93	−3.87	7.53	8.47	8.37	20.0
2001:M1	1999:M1–2000:M6	−4.68	−5.03	−5.82	−8.77	5.86	5.63	7.75	10.4
	2002:M1–2003:M12	−1.78	−2.52	−2.16	−3.38	0.23	0.28	0.25	0.38

Notes: The numbers show the estimated policy reaction function for the one-month horizon. Base: two-variable baseline model, IP: three-variable model with industrial production, CMP: three-variable model with the world commodity price index, 2P: three-variable model with the two policy instruments.

However, the increases in estimated policy reactions in the three-variable models do not change our main conclusion on the exchange rate policies of crisis countries. The increases are found in almost all countries, not only in benchmark countries but also in crisis countries. Because the inference on the exchange rate policy of crisis countries is conducted in comparison with the benchmark cases, the main conclusion does not change much.

On the other hand, the exchange rate stabilization of the central bank can also help central banks' other objectives such as output and inflation stabilization. Therefore, it is difficult to infer the ultimate policy goals of the central banks from the policy reaction functions (to exchange rate shocks) identified in this study. A future study, possibly estimating the policy reaction functions including more variables to the model, will be conducive to clarify the issue.

Second, other benchmark countries were used to check the robustness of the main results. As the benchmark for a free floater, the most popular free floater, the United States, was considered. Since the United States often intervenes its exchange rate against two currencies—the DM (or euro) and the Japanese yen—two models, one against the DM (or euro) and the other against the Japanese yen, were constructed. The size of policy reactions of the United States has been similar to that of Japan.[20] As the benchmark for a very tightly managed exchange rate regime, Hong Kong, which has adopted the currency board system, was considered. Hong Kong has been keeping its exchange rate against U.S. dollars very tightly, even more tightly than Denmark. The size of reactions has turned out to be even stronger than those of Denmark.[21] When these benchmark countries are also used, the main conclusions do not change.

Third, experiments were performed with various measures of foreign exchange reserve changes such as percentage changes in foreign exchange reserves and foreign exchange reserve changes as a

[20] The reserve and interest rate reactions of the United States against the Japanese yen for the period 1983–2003 are 0.08 to 0.09 and –0.24 to –0.59, respectively. Those against the DM for the period 1983–98 are 0.11 to 0.09 and –0.30 to –1.23, respectively. Those against the euro for the period 1999–2003 are 0.06 to 0.05 and –0.17 to –0.84, respectively.

[21] The reserve and interest rate reactions of Hong Kong are –198.14 to –252.18 and 20.57 to 15.05, respectively, for the period 1996:M12–2003:M12 (the data availability dictates this choice of estimation period).

percentage of the average monetary base during the sample period. The main results do not change.

4.2 Comparison with Methodology of Calvo and Reinhart (2002)

The results using the methodology developed in this paper are now compared with the results based on Calvo and Reinhart's (2002) methodology in order to discuss some shortcomings of Calvo and Reinhart (2002). For this purpose, the two methods of Calvo and Reinhart (2002) are applied to the same samples. First, Calvo and Reinhart (2002) used the probabilities that the absolute value of the percentage changes in the exchange rate, foreign exchange rate reserve, and the interest rate are lower than the threshold values. A lower probability for the exchange rate (that is, more volatile exchange rate changes) and higher probabilities for the policy instruments (that is, less volatile policy instrument changes) are regarded as indicating a more flexible exchange rate arrangement. Second, Calvo and Reinhart (2002) used the exchange rate flexibility index, the ratio of the variance of the percentage changes in the exchange rate to the sum of the variances of the interest rate changes and the variance of the percentage changes in foreign exchange reserves. A larger number suggests a more flexible exchange rate arrangement, since a larger number should be related to a larger variation in the exchange rate and lower variations in the policy instruments.

Table 7 reports the probability that each variable changes less than 1 percent as well as the exchange rate flexibility index (EFI).[22] The index reasonably explains the relative degree of exchange rate flexibility for the benchmark cases; Japan has a higher number than Australia and Australia has a higher number than Denmark. However, the exchange rate flexibility numbers often fail to capture the relative rankings of exchange rate flexibility. The index numbers of the benchmark free floaters seem to be too small compared with the index numbers of crisis countries. There are nine cases in which the index numbers of crisis countries are higher than that of Australia (the post-crisis periods of South Korea, Indonesia, the Philippines,

[22]When different threshold values are used, the main conclusion remains unchanged.

Table 7. Measures of Calvo and Reinhart (2002)

Country vs. Crisis Date	Estimation Period	Probability (< 1%)			EFI
		E	FR	R	
Japan ($)	1983:M1–2003:M12	33.1	55.0	99.2	0.80
Australia ($)	1984:M1–2003:M12	31.0	23.8	93.3	0.14
Denmark (DM)	1979:M3–1998:M12	92.4	13.5	78.5	0.00
	1999:M1–2003:M12	100.0	15.3	100.0	0.00
Korea ($)	1992:M1–1996:M12	88.1	27.1	61.0	0.05
1997:M9	1999:M1–2003:M12	42.2	33.9	100.0	1.37
Indonesia ($)	1992:M1–1996:M12	98.3	40.7	69.5	0.01
1997:M6	1999:M1–2001:M6	13.3	30.0	50.0	1.10
	2001:M7–2003:M12	34.5	48.3	41.4	2.82
Philippines ($)	1992:M1–1996:M12	62.7	11.9	42.4	0.03
1997:M6	1999:M1–2003:M12	57.6	27.1	88.1	0.26
Malaysia ($)	1992:M12–1996:M12	72.9	27.1	100.0	0.03
1997:M6	1999:M1–2003:M12	100.0	32.2	98.3	0.00
Thailand ($)	1992:M12–1996:M12	98.3	30.5	30.5	0.02
1997:M7	1999:M1–2001:M6	37.1	42.9	88.6	0.88
	2001:M7–2003:M12	51.7	20.7	100.0	0.30
Mexico ($)	1989:M1–1993:M12	67.8	18.6	30.5	0.00
1994:M11	1997:M1–2003:M12	50.0	33.3	52.8	0.29
Brazil ($)	1994:M7–1997:M12	75.6	26.8	41.5	0.01
1998:M12	2000:M1–2003:M12	17.0	27.7	76.6	0.42
Russia ($)	1995:M8–1997:M12	53.6	0.0	10.7	0.00
1998:M7	1999:M10–2000:M11	61.5	0.0	15.4	0.09
	2000:M12–2003:M12	80.6	16.7	27.8	0.01
Ecuador ($)	1995:M11–1998:M12	18.9	8.1	32.4	0.13
1999:M12	2001:M1–2003:M12	100.0	39.1	100.0	0.00
Bulgaria (DM)	1993:M12–1995:M12	20.8	4.2	58.3	0.11
1996:M12	1997:M7–1998:M12	100.0	17.6	94.1	0.00
	1999:M1–2003:M12	98.3	11.9	64.4	0.00
Turkey (DM)	1993:M7–1998:M6	6.8	11.9	10.2	0.02
2001:M1	1999:M1–2000:M6	23.5	17.6	35.3	0.02
	2002:M1–2003:M12	17.4	26.1	47.8	0.85

Note: The numbers show the respective probability measures for the exchange rate (E), the foreign exchange reserves (FR), and the interest rate (R), and the exchange rate flexibility index (EFI), developed by Calvo and Reinhart (2002).

Thailand, Mexico, Brazil, and Turkey). In four cases (the post-crisis periods of South Korea, Indonesia, Thailand (1999–2001:M6), and Turkey), the numbers are even higher than that of Japan. It is quite difficult to believe that the degree of exchange rate flexibility of all the aforementioned countries is higher than that of Australia and Japan. This problem also arises for some cases in the pre-crisis period. For example, the number for Ecuador in the pre-crisis period is 0.13, which is similar to that of Australia (0.14), but it may be difficult to believe that the pre-crisis exchange rate arrangement of Ecuador was as flexible as that of Australia.

In addition, there are at least three cases in which the conclusion on the classification of free floating based on Calvo and Reinhart (2002)'s exchange rate flexibility index is different from the one based on the methodology developed in this paper. The exchange rate flexibility index of Turkey for the post-crisis period (0.85) is larger than those of Japan and Australia, the index of Brazil for the post-crisis period (0.29) is larger than that of Australia, and the index of Ecuador for the pre-crisis period (0.13) is similar to that of Australia. Although these countries are classified as intermediate regimes based on the measures developed in this paper, they are likely classified as free floating based on the exchange rate flexibility measure of Calvo and Reinhart (2002).

Next, the probability measures are examined. For benchmark cases, Australia seems to have a less flexible arrangement than Japan; while the probability that the percentage exchange rate changes are lower than 1 percent is similar for both countries, the probability that the percentage changes in foreign exchange reserve are lower than 1 percent is far lower in Australia than that in Japan, and the probability that the changes in the interest rate are lower than 1 percent is also lower in Australia than that in Japan, which implies policy instruments have higher volatilities in Australia than in Japan. Denmark has a higher probability for exchange rate changes (or a lower exchange rate volatility) and lower probabilities for policy instrument changes (or higher volatilities of policy instruments) than Japan and Australia, as expected.

However, it is often difficult to make a clear conclusion on whether one country has a tighter exchange rate arrangement than the benchmark countries based on probability measures because the probabilities for both policy instruments and the exchange rate are larger (or smaller) in one country than those in benchmark countries. For example, in the cases of post-crisis South Korea, Ecuador, and Malaysia and pre-crisis Malaysia, all probabilities are higher in crisis countries than those in Australia. In the case of the pre-crisis periods of Ecuador, Bulgaria, and Turkey, all probabilities are lower in crisis countries than those in Australia. There are many more cases in which the probabilities for at least one policy instrument and the exchange rate are larger (or smaller) in crisis countries than those in Australia. The difficulty in this comparison arises mostly because at least two numbers (one for exchange rate and one for policy instruments) should be compared, and it is not so easy to have a clear conclusion with the two numbers that have possibly different implications on the size of policy actions.[23]

To summarize, although the probability measures developed by Calvo and Reinhart (2002) provide useful information, it is often difficult to use the measures to make a comparison across different sample periods and countries. On the other hand, the exchange rate flexibility measures developed by Calvo and Reinhart (2002) sometimes provide results that seem unreasonable, but they still provide a good summary measure that can be easily adopted to compare across different countries and sample periods. Overall, in addition to the conceptual advantage of the measure developed in this paper over those of Calvo and Reinhart (2002), there seem to be practical advantages as well.[24]

5. Conclusion

This paper first develops a method to identify the de facto exchange rate arrangements using a structural VAR model with sign restrictions on impulse responses. The method improves upon the

[23]For example, suppose that the numbers for policy instrument and exchange rate are 20 percent higher in one case than the other case. Then, it is difficult to interpret the results because a 20 percent higher probability of each variable is not clearly related to policy actions, and it is difficult to judge whether it implies more flexible exchange rate arrangements.

[24]However, the current methodology has two shortcomings compared with Calvo and Reinhart (2002). First, the analysis itself is more complicated. Second, application of the analysis is more suited to a longer sample period because a multi-variable time-series model is estimated.

previous methodologies, as it uses only relevant information for inferring exchange rate stabilization, and it formally derives the policy reaction function.

By applying the method to the countries that have experienced a severe crisis, the exchange rate policy transition around the crisis period is examined. In the post-crisis period, a large fraction of these countries have moved to bipolar regimes—either hard pegs, such as a currency board and dollarization, or more flexible exchange arrangements that are close to a free float. This is consistent with the bipolar view. Countries often overstate their exchange rate flexibility, but such a tendency is a bit weaker in the post-crisis period than in the pre-crisis period. Indeed, these countries seem to have learned from their crises. By moving toward polar regimes, they seem to be trying to lower the possibility of a future crisis in integrated capital markets. They may have also learned that just saying is not enough since they experienced crisis regardless of what they had said.

Appendix

This appendix explains details on the implementation of the sign restrictions discussed in the main text of this paper. The reduced-form VAR equations can be written as $Y_t = A(L)\varepsilon_t$, where Y_t is an n×1 data vector, $A(L)$ is an n×n matrix polynomial in lag operator L, ε_t is a serially uncorrelated n×1 vector of residuals in the reduced-form equation, and $\text{var}(\varepsilon) = \Sigma$. Finding the structural form amounts to finding an n×n matrix, K, such that $\varepsilon_t = Ke_t$, where $\text{var}(e_t) = I_n$. Cholesky factorization of Σ is one example of finding a structural form. That is, a Cholesky factor, P, can be used as K, where $\Sigma = PP'$ and P is a Cholesky factor. Also, note that PN, where N is an n×n orthonormal matrix (i.e., $NN' = I_n$) can be regarded as K. As discussed in Uhlig (2005), the space of K is spanned by N given P. $A(L)$ and Σ are drawn from normal Wishart distribution. To draw N, some elements of N are drawn from the standard normal distribution and other elements are recovered by using the restrictions that are implied by $NN' = I_n$.

For the two-variable model, I draw each element in the first row of N from the standard normal distribution and normalize to have the norm of 1 (which is implied by $NN' = I_n$). The second row of N is derived from the restriction $NN' = I_n$ given the drawn two elements of the first row of N. For the three-variable model, I draw each element in the first row of N from the standard normal distribution and normalize to have the norm be 1. In the case of the three-variable model, another element in N is still needed to recover all elements of N. Thus, I draw each element in the second row of N from the standard normal distribution and normalize them to have the norm to be 1. Since only one element is needed, I only use the first element of the second row, and discard other elements. The remaining five elements are drawn from the restriction $NN' = I_n$ given four drawn elements.

I generate 10,000 draws and keep the draws that satisfy the sign restrictions, while discarding the draws that do not, and then calculate the median impulse responses and probability bands. The policy reaction function is calculated for each draw kept, and then the median and the probability bands are calculated. For simulation experiments to compare the size of policy reactions between the two cases, I compare the sizes of policy reactions for each draw kept, and calculate the probability that the size of policy reactions of one case is not larger (or smaller) than that of the other case. For the two-variable model of the exchange rate and the foreign exchange reserve, I discard the draws where both shocks move two variables in the same direction or in opposite directions. I keep the draws where one shock moves two variables in the same direction and the other shock moves two variables in opposite directions, and define the former as the shocks to the foreign exchange reserves and the latter as the shocks to the exchange rate. For other models, a similar procedure is used.

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Which Aspects of Central Bank Transparency Matter? A Comprehensive Analysis of the Effect of Transparency on Survey Forecasts*

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We investigate whether a higher level of central bank transparency can reduce the degree of disagreement across individual forecasters, and whether it can improve the forecasting performance of survey respondents. The analysis is carried out on a panel data set that is richer than those used by previous studies. This unique data set allows us to test both for causality and for misspecification. Moreover, it allows us to identify the effects of various aspects of transparency separately and to assign weights to them reflecting their relative importance in reducing uncertainty. Finally, we construct a new composite measure of transparency using the estimated weights.

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1. Introduction

There is no consensus in the literature with regard to how the degree of central bank transparency influences the level of uncertainty in the economy and thereby the economic performance of a country. In

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this paper we contribute to the literature by investigating empirically whether higher transparency can reduce the uncertainty regarding both future monetary policy and future macroeconomic outcomes. In addition, we analyze what aspects of transparency are important (if any).

A number of empirical and theoretical studies claim that central bank transparency has a *favorable* effect on the economy. These studies are Chortareas, Stasavage, and Sterne (2002), Crowe and Meade (2008), Demertzis and Hughes Hallett (2007), Dincer and Eichengreen (2010, 2014), Ehrmann, Eijffinger, and Fratzscher (2012), Middeldorp (2011), and Swanson (2004), inter alia. Some other papers, however, come to a different conclusion. The papers of van der Cruijsen, Eijffinger, and Hoogduin (2010), Dale, Orphanides, and Österholm (2011), Demertzis and Hoeberichts (2007), Kool, Middeldorp, and Rosenkranz (2011), Morris and Shin (2002), Neuenkirch (2013), and Walsh (2007) find either that higher transparency is *unfavorable* or that it has an *ambiguous* effect on mitigating the uncertainty.

This paper finds central bank transparency to have a mostly *favorable* effect on the economy, as it mitigates uncertainty. Our strategy to identify the relationship between transparency and uncertainty is the following. We run panel regressions where the dependent variable is a proxy for uncertainty (it measures the quality of survey forecasts on a number of economic indicators), while the independent variable is the most commonly used measure on central bank transparency developed by Eijffinger and Geraats (2006).[1] More precisely, our independent variable is the composite Eijffinger-Geraats index, one of its five sub-indices, or one of its fifteen components.

We use a *unique panel data set* that is richer in both of its dimensions than any of those used by previous panel analyses in the literature.[2] The number of countries in our data set is twenty-six, and

[1]The Eijffinger-Geraats index is used, for example, by the empirical works of Csavas et al. (2011), Demertzis and Huges Hallett (2007), Dincer and Eichengreen (2007), Ehrmann, Eijffinger, and Fratzscher (2012), Middeldorp (2011), Siklos (2011), and van der Cruijsen, Eijffinger, and Hoogduin (2010).

[2]The panel analyses of Middeldorp (2011) and Neuenkirch (2013) cover almost as many countries as ours. Their panel data set includes twenty-four and twenty-five economies, respectively.

the sample covers the period between October 1989 and December 2009. The most remarkable feature of our data is that there is *high enough variation* in almost all measurable aspects of transparency to identify their effects on the quality of forecasts. Previous papers were unable to study the effects of each of the fifteen components of the Eijffinger-Geraats index due to insufficient variation in their data.

It is also a unique feature of our data that allows us to test for causality by the Granger causality test. When testing for causality, it is crucial to know the exact timing of changes in transparency; otherwise, we do not know whether a reform in transparency is preceded or followed by a change in the quality of forecasts. Unfortunately, the original Eijffinger-Geraats index has a lower frequency than the monthly survey forecasts. Most likely, it is the difference between the frequencies that prevented previous studies from testing for causality. We circumvent the problem by harmonizing the data frequencies, i.e., we construct the monthly time series of the Eijffinger-Geraats index and sub-indices by collecting information on the timing of reforms in transparency for a subset of countries in our sample. The results of the causality tests obtained on this sub-sample of countries with monthly frequency are mixed: one-way causality is supported only by one-quarter of all the investigated specifications. However, more than two-thirds of these specifications suggest that higher transparency causes better forecasts.

Our strategy to identify the effect of central bank transparency is similar to that of the most comprehensive empirical analysis on the subject in Ehrmann, Eijffinger, and Fratzscher (2012). They also identify the relationship between transparency and uncertainty by running panel regressions. Their dependent variable also measures the quality of survey forecasts on a number of economic indicators, and their independent variable is either (i) the composite Eijffinger-Geraats index or (ii) the economic sub-index of the Eijffinger-Geraats index, or it captures (iii) whether a central bank announces a quantified inflation objective or (iv) whether a central bank publishes its internal forecasts for inflation and output. However, we deviate from their approach in some important respects.

First, the aim of this paper is not only to shed light on the effects of some selected measures of transparency, but also to analyze the *effects of each measurable dimension of transparency separately.*

Therefore, we also run regressions on those specifications where transparency is measured by the components of the Eijffinger-Geraats index.

Second, our purpose with this detailed analysis is to help central bankers decide what specific aspects of transparency should be improved. To do that, we have to test whether a higher degree of transparency can cause lower uncertainty. We think that *testing causality* is crucial from a normative perspective.[3]

Third, we proxy uncertainty not only by a measure on the dispersion of views of the individual forecasters but also by the absolute forecast error. The motivation for that is provided also by the working paper by Ehrmann, Eijffinger, and Fratzscher (2010), in which they write: "It is also important to test how forecast accuracy is affected, as we need to ensure that transparent and communicative central banks do not align forecasts at *lower* levels of accuracy." This paper points out that their parameter estimates regarding the effect of transparency on forecast accuracy are biased, unfortunately.

Our fourth contribution relates to learning the magnitude of the *bias* and also to *eliminating* it. Here, the idea is to estimate the model not only on those variables whose forecasts are hypothesized to be influenced by central bank transparency, but also on oil price, which is exogenous to monetary policy.[4] When working with the model and data frequency used by Ehrmann, Eijffinger, and Fratzscher (2010), we detect *misspecification* by finding a significant relationship between some measures of transparency and oil price forecast errors. However, when working with a modified version of the Ehrmann, Eijffinger, and Fratzscher (2010) model and data with different frequency, the oil price predictions seem to be independent of transparency, as is in line with our intuition. In addition to the oil price regressions, econometric theory also underpins that both the parameter estimates and the estimated standard errors are biased when following the methodology of Ehrmann, Eijffinger, and Fratzscher (2010) or Ehrmann, Eijffinger,

[3]Ehrmann, Eijffinger, and Fratzscher (2012) do not test whether the relationship between transparency and uncertainty is causal.

[4]Whether oil price is unaffected by monetary policy in general, and especially by monetary policies of large economies such as the United States or China, is not obvious. The test of Kilian and Vega (2011), however, underpins oil price exogeneity.

and Fratzscher (2012), while neither of these problems arises with our methodology.

The composite Eijffinger-Geraats index is criticized for being an *equally weighted* sum of its components.[5] Even Eijffinger and Geraats (2006) share the view that the weights of the components of the composite index should be established empirically. To the best of our knowledge, this paper is the first that fills the gap by *constructing a weighted index of central bank transparency*. The index we propose aggregates the same fifteen components as the composite Eijffinger-Geraats index. The weights we assign to the components are estimated and reflect the relative importance of the components in reducing uncertainty. Our purpose with publishing the weights and the weighted composite transparency index is to give central bankers guidance about which types of transparency have worked best so far. We find that the best practice of central banking involves (i) preparing and publishing own forecasts, (ii) providing an explicit policy rule or strategy that describes the monetary policy framework, and (iii) promptly announcing policy decisions.

The rest of the paper is structured as follows. Section 2 presents our benchmark econometric model. Section 3 describes our data set. Section 4 presents the results obtained with the benchmark model. It also presents a number of robustness checks and the Granger causality tests. Finally, it introduces the weighted transparency index. The conclusions are presented in section 5.

2. Benchmark Regression Model

This section describes our benchmark model, which is a modified version of the Ehrmann, Eijffinger, and Fratzscher (2012) model.[6] The model is given by

[5]For instance, Claussen (2008) argues that the Eijffinger-Geraats index can be misleading, because its crude scores blow up the difference between countries, and the equal weighting does not take into account that some aspects are more important for transparency than others.

[6]The main difference between our model and that of Ehrmann, Eijffinger, and Fratzscher (2012) is that the former is static, while the latter is a dynamic one. Our motivation to deviate from the approach of Ehrmann, Eijffinger, and Fratzscher (2012) is discussed in section 4.1.

$$y_{i,t} = \beta x_{i,t} + \alpha_i + \gamma_1 \sigma_{i,t} + \gamma_2 \left|\Delta \text{oil}_{t-1}\right| + \epsilon_{i,t}, \tag{1}$$

where $y_{i,t}$ denotes the dependent variable characterizing the forecasts in country i at time t. More precisely, it measures the quality of forecasts either by the degree of disagreement across individual forecasters or by the forecast accuracy. The measure on central bank transparency in country i at time t is denoted by $x_{i,t}$. To be more specific, $x_{i,t}$ can be the composite transparency index, one of its five sub-indices, or one of its fifteen components.

The main parameter of our interest is β. Our hypothesis is $\beta < 0$, i.e., forecasters disagree less and make smaller forecast errors if the central bank is more transparent. The only forecasted variable where the hypothesis is different from the above is the oil price. As the oil price is considered to be exogenous to monetary policy, the corresponding hypothesis is $\beta = 0$.

We control for country fixed effects by α_i. *The country fixed effect* captures some unobserved country-specific characteristics, such as how difficult it is in general to predict some country-specific economic indicators, and also what is the overall level of skills of the forecasters in the country.

In addition to the country fixed effects, we include the conditional volatility of the variable to be forecasted $\sigma_{i,t}$,[7] and the absolute change in oil price in the previous period $|\Delta \text{oil}_{t-1}|$. We expect that the higher the volatility of the economic indicator to be forecasted, the higher the degree of disagreement and the less precise the forecasts ($\gamma_1 > 0$). Finally, larger absolute changes in oil price are likely to be associated with higher general uncertainty in the oil-dependent globalized world economy that may increase both the degree of disagreement and the forecast errors ($\gamma_2 > 0$).

We estimate model (1) in *levels,* as we find evidence for a unit root neither in the processes of the sub-indices and the composite Eijffinger-Geraats transparency index, nor in the processes of almost all the dependent variables.[8] All the regressions are estimated by the *least square dummy variable* (LSDV) estimator. Standard errors are calculated by the White cross-section method that is designed to accommodate arbitrary heteroskedasticity.

[7]Section 3.3 discusses in detail how the conditional volatility is measured.

[8]See Csavas et al. (2012) for the details of the unit-root tests.

3. Data

In our empirical exercise, we use data on the transparency index, survey forecasts on various macro variables, and historical data of the same set of variables. This section provides a detailed description of these data.

Our data cover twenty-six countries. Twelve of them are advanced economies. These countries are Canada, France, Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the United States. In addition to the developed countries, our sample covers also fourteen European emerging countries: Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Russia, Slovakia, Slovenia, Turkey, and Ukraine.

Our panel data comprises 243 periods from the monthly sample between October 1989 and December 2009. However, the benchmark estimates are carried out on a sample restricted in two ways. First, it consists of forecasts with *non-overlapping forecast horizons*, i.e., if the forecast horizon is M months, then we sample every Mth observation from the monthly data. Second, the estimates are obtained on a *shorter period* that spans between January 1998 and December 2009. The cost of avoiding overlapping forecast horizons and working with a short sample period is that the time dimension of our sample reduces substantially. Later, we argue in favor of estimating the model on the restricted sample and present the relevant sensitivity analyses.

3.1 Data on Central Bank Transparency

Although the concept of central bank transparency is rather complex, there is a forming agreement on its definition. Still, it is difficult to find reasonable quantitative measures for it. In the literature, the most commonly used transparency measure is the one constructed by Eijffinger and Geraats (2006). Others, such as Minegishi and Cournède (2009), propose alternative measures. We opt to use the Eijffinger-Geraats index for most of our analyses and the Minegishi-Cournède index for a robustness check. The main advantage of the Eijffinger-Geraats index is that it has the broadest coverage of countries and periods due to the work by Dincer and Eichengreen (2007) and Siklos (2011), who have expanded and updated the original sample of Eijffinger and Geraats (2006). We use the latest update of the Eijffinger-Geraats index by Siklos (2011) with some minor modifications.[9]

The *sample* of the latest update of the transparency index spans between 1998 and 2009. Therefore, our benchmark estimates are carried out on this sample period. However, in some instances, we work with a sample *lengthened* by the period between 1989 and 1997 for which survey forecasts are available. Ehrmann, Eijffinger, and Fratzscher (2012) also lengthen their sample by a period preceding 1998 to enrich the data used in their benchmark estimation. They apply the 1998 values of the indices for a given country to all years prior to 1998. As we could not find convincing evidence for no progress in transparency in the investigated countries before 1998,[10] and our sample is rich enough even without this way of producing extra observations, we start our sample in 1998 in the benchmark estimation. But we present estimates on the longer sample, generated the same way as Ehrmann, Eijffinger, and Fratzscher (2012) do, as part of the robustness checks.

The data frequency of the Eijffinger-Geraats transparency index is annual, while the survey forecasts are on monthly frequency. We harmonize the data frequencies in two different ways. First, we transform the data on transparency into monthly by assigning the annual value to each of the twelve months in the given year. Almost all the analyses in this paper are carried out on data harmonized in this way. Second, we construct the monthly time series of the Eijffinger-Geraats index and sub-indices for a selected group of countries by

[9]The Czech National Bank and the Central Bank of Hungary have been publishing individual voting records since 2008 and 2005, respectively. As these developments in transparency are not captured by the updated index by Siklos (2011), we make the following corrections. We change the score of the 3C component from 0.5 to 1 for both countries for the relevant periods. Furthermore, Slovakia introduced the euro in January 2009, and therefore we assign the values of the transparency indices of the European Central Bank to Slovakia since then.

[10]The reforms in the Sveriges Riksbank are counterexamples for having no progress in transparency before 1998. The Swedish central bank started announcing its inflation target in 1993 and started publishing inflation forecasts in 1995. Some further changes in transparency in nine central banks between 1989 and 2003 are collected by van der Cruijsen and Demertzis (2005) in their appendix B2.

collecting information on the timing of reforms in transparency. We use this method of frequency harmonization only for the Granger causality test, where it is crucial to learn the exact timing of changes in transparency.

The Eijffinger-Geraats index measures five distinct dimensions of transparency in the policymaking process. The first dimension, *political transparency*, concerns the central bank's openness about its policy objectives—in particular, whether it announces quantitative targets, formal goals, and the priority of these goals. The institutional arrangements, such as central bank independence and codification of roles and responsibilities of the central bank, are also vital elements of the political dimension of transparency. The second dimension, *economic transparency*, refers to the central bank's willingness to release information relevant for monetary policy, including economic data, forecasts, and policy models. Sharing this information with the public allows independent, external assessment of monetary policy decisions. The third dimension, *procedural transparency*, gauges how monetary policy decisions are made and whether an explicit policy rule or strategy is provided that the decision makers follow. This dimension indicates also whether the central bank publishes minutes and voting records that document how its policymaking committee arrives at its decisions. The fourth dimension, *policy transparency*, is about the timely communication of the policy decisions, whether decisions are announced promptly following the committee meetings, whether the public is provided with a detailed explanation underlying the decisions, and finally, whether these explanations include signals of policy inclination or explicit indication of likely future policy actions. The last distinct dimension, *operational transparency*, focuses on the implementation of monetary policy—in particular, the degree of control over the main operating instrument, whether the central bank publishes its forecast errors made in the past, and whether it assesses the attainment of its targets with the contribution of monetary policy in that achievement.

All five dimensions have three components. Out of the fifteen components, six score either 0 or 1, while nine of them score either 0, 1/2, or 1. A higher score corresponds to a higher level of transparency. The composite index, or total index, is calculated as the sum of the sub-indices. Accordingly, the total Eijffinger-Geraats index can have a minimum value of 0 and a maximum value of 15. The scoring system is summarized by the left panel of table 1.

The main advantage of our rich panel data is that the transparency indices exhibit substantial variation. When comparing the *variation in the transparency index* in all twenty-six countries in our data with that in the twelve advanced countries examined also by Ehrmann, Eijffinger, and Fratzscher (2012), we see that the emerging countries contribute to the variance of the total transparency index twice as much as the advanced countries do (680 percent/334 percent; see the right panel of table 1). And also, most of the sub-indices and components are more dispersed in the sample of twenty-six countries than in that of the twelve advanced economies. The excess variation that we gain by enlarging the sample with the emerging countries enables us to estimate the effect of each of the sub-indices on the quality of forecasts. Moreover, it also allows us to assess the optimal weighting of the fifteen components and to aggregate them to an economically meaningful composite index.

A further feature of our panel data is that the cross-sectional variance of transparency is much larger than the time-series variance. This suggests that empirical identification of any relationship between transparency and quality of forecasts comes mainly from the heterogeneity of the countries and marginally from the dynamics over time.

3.2 Data on Dependent Variables

The dependent variable in equation (1) measures either the degree of disagreement across individual forecasters or the forecast accuracy. For the former, we exclusively use the survey data of Consensus Economics. For the latter, we use historical data of the forecasted economic indicator in addition to the forecasts.

Consensus Economics surveys a large group of professional forecasters. It reports the arithmetic average and the standard deviation of the individual forecasts. The former is called the consensus forecast. We measure the *forecast accuracy by the absolute forecast error* of the consensus forecast, while the *degree of disagreement* is measured by the *standard deviation of the individual forecasts,* as these statistics are readily available to us.

Table 1. Scoring System of the Eijffinger-Geraats Transparency Measures and the Variance of the Components, Sub-Indices, and Total Eijffinger-Geraats Index by Country Groups (sample: Jan. 1998–Dec. 2009, 26 countries)

	Theoretical Scores			Sample Variance		
				Country Groups		
	Min.	Intermediate Value of Components	Max.	12 Advanced	14 Emerging	All 26
1A. Formal Objectives	0	1/2	1	6%	4%	5%
1B. Quantitative Targets	0		1	16%	21%	19%
1C. Institutional Arrangements	0	1/2	1	3%	5%	4%
1. Political Transparency	0		3	50%	46%	48%
2A. Economic Data	0	1/2	1	4%	9%	14%
2B. Policy Models	0		1	23%	16%	24%
2C. Central Bank Forecast	0	1/2	1	12%	16%	18%
2. Economic Transparency	0		3	55%	66%	108%
3A. Explicit Strategy	0		1	14%	21%	18%
3B. Minutes	0		1	22%	10%	17%
3C. Voting Records	0	1/2	1	21%	5%	14%
3. Procedural Transparency	0		3	53%	58%	64%
4A. Prompt Announcement	0		1	0%	25%	19%
4B. Policy Explanation	0	1/2	1	6%	10%	15%
4C. Policy Inclination	0		1	11%	0%	6%
4. Policy Transparency	0		3	22%	61%	75%
5A. Control Errors	0	1/2	1	3%	8%	22%
5B. Transmission Disturbances	0	1/2	1	8%	6%	8%
5C. Evaluation of Policy Outcomes	0	1/2	1	4%	6%	5%
5. Operational Transparency	0		3	21%	29%	53%
Total Index	0		15	334%	680%	966%

The list of economic indicators that are forecast consists of the three-month interest rates (in percent),[11] ten-year government bond yields (in percent), the consumer price index (CPI, percent change per annum), the growth rate of real gross domestic product (GDP, percent change per annum), the consumption growth (percent change per annum), and the oil price (WTI price in U.S. dollars).

We apply the following simple *transformation* to the oil price forecasts. We transform the forecasts and their standard deviations into percentage changes relative to the nominal oil price on the survey day. Without this transformation the uncertainty of oil price forecasts are not directly comparable across periods with substantially different nominal spot oil prices.

The *sample* of survey forecasts spans between October 1989 and December 2009, but the time series are shorter for some countries in our unbalanced panel.[12] Both the interest rates and the oil price are forecasted for fixed horizons of three months and twelve months, while all the other variables are forecasted for the end of the current year and the end of the following year.

The *frequency* of the survey data is monthly, except for the emerging countries prior to June 2007, when it is only bimonthly. For our benchmark estimates, we use only a sub-sample of the available survey data with lower than monthly frequency in order to avoid having overlapping forecast horizons. For instance, we sample every third observation from the three-month forecasts, every twelfth observation from the twelve-month forecasts and end-of-year forecasts, and every twenty-fourth observation from the end-of-next-year forecasts. These non-overlapping samples usually start with the forecast round in January 1998 in the benchmark case.[13]

[11]The forecasted short rate is the overnight interbank interest rate for Turkey, while it is the three-month rate for all the other countries.

[12]The sample period of most of the advanced countries spans between October 1989 and April 2009 and covers 235 forecast rounds. The exceptions are the Netherlands, Spain, and Sweden, whose sample starts in January 1995, and Norway and Switzerland, whose sample starts in June 1998. The sample period for most of the emerging countries spans between January 2003 and December 2009 and covers fifty-eight forecast rounds. The exceptions are Bulgaria, Croatia, Estonia, Latvia, Lithuania, and Slovenia, whose sample starts in May 2007.

[13]The only exception is the case of the end-of-next-year forecasts, where we start the non-overlapping sample with the forecast round in January 1999 in order to maximize the sample size.

In order to assess forecast accuracy, we need *historical data* of the forecasted economic indicators. These data are mainly from the OECD's Main Economic Indicators database. For some non-OECD countries (Bulgaria, Croatia, Latvia, Lithuania, Romania) the historical data are from the European Commission's annual macroeconomic (AMECO) database. We also use the International Monetary Fund's International Financial Statistics (IFS) database to cross-check the data, and expand the time series where possible. Short-term and long-term interest rates are from Bloomberg. The data source of the oil price is Thomson Reuters Datastream.

3.3 Data on Control Variables

In order to judge how transparency affects the quality of forecasts, we control for the overall difficulty of forecasting. The control variables are the absolute change in oil price in the previous month $|\Delta \text{oil}_{t-1}|$ and the conditional volatility of the forecasted variable $\sigma_{i,t}$ in addition to the fixed effects.

The *conditional volatility* is constructed by following the approach of Capistran and Timmermann (2009) and Ehrmann, Eijffinger, and Fratzscher (2012), i.e., by estimating GARCH(1,1) models for the time series of each economic indicator separately. We include the first and the second lags of the variable in question into the mean equation. This way we handle the persistency of the time series. For estimating the conditional volatility of time t, we use not only those data that are available at time t, but also historical data from the period between 1980 and 2009. As the frequency of most of the historical data is annual, so is that of the estimated conditional volatility. The exceptions are the interest rates and oil price changes, where the frequency is monthly.

4. Empirical Analysis

In this section, we estimate the benchmark model and some alternatives of it. The alternative estimates serve to (i) check the robustness of the benchmark results, (ii) test whether the estimated relationship between transparency and quality of forecasts is causal, and (iii) construct the weighted transparency index.

4.1 Estimation Results with the Benchmark Model

This section presents and interprets the results of 144 regressions run on twenty-four distinct dependent variables by using one of the six transparency indices as an explanatory variable. As a reminder, the six transparency indices are the five sub-indices together with the total Eijffinger-Geraats index. There are twenty-four different dependent variables: six economic variables are forecasted for two different horizons each, and the forecasts are characterized either by their dispersion or by their accuracy.

Tables 11 and 12 in the appendix report the regression results for the dispersion of forecasts and the forecast accuracy as the dependent variable, respectively.[14] In order to help the reader process the tremendously large amount of information presented in these tables, we summarize the results on the main parameter of our interest, β, in table 2. This table shows the sign and significance of the estimated coefficient capturing the effect of transparency.

We start the interpretation with the results of the *oil price regressions*. It is important to see that we estimate the oil price regressions with a completely *different motivation* than the other regressions with macro variables. We do not think that central bank transparency should affect oil price forecasts by any means, as oil price is exogenous to monetary policy. However, its exogeneity helps us detect if the model is *misspecified* or the *estimation method is not adequate* for the given model. The results of the oil price regressions are presented in the last two rows of table 2. With the exception of one marginally significant coefficient estimates, our hypothesis of $\beta = 0$ cannot be rejected.[15] Therefore, model (1) with the applied estimation method (LSDV) is likely to be adequate to investigate the relationships between different aspects of central bank transparency and macro forecasts.

[14]Most of the estimates reported in tables 11 and 12 support our hypotheses with secondary importance. These hypotheses are (i) the positive relationship between the volatility of the variable to be forecasted and the dependent variable ($\gamma_1 > 0$) and (ii) the positive relationship between the absolute changes in oil price and the dependent variable ($\gamma_2 > 0$).

[15]We obtain qualitatively the same result if we start the non-overlapping subsample with the forecast round in any month other than January. That is, the coefficient of the transparency measure is significant only in a few specifications of the oil price regressions.

Table 2. Sign and Significance of the Estimated Effect of Transparency on the Quality of Forecasts: Summary of 144 Regressions with Different Specifications of the Benchmark Model (1) (sample: Jan. 1998–Dec. 2009, 26 countries, non-overlapping forecast horizons)

Transparency Index →	Political		Economic		Procedural		Policy		Operational		Total	
	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE
Short Rate - 3M	− − −	−		− − −					− −	− −		− − −
Short Rate - 1Y	−		−								−	
Long Rate - 3M					+++							
Long Rate - 1Y			− −	−								
CPI - CY			− −	−							− −	
CPI - NY		++	− − −				− − −			++	− − −	
GDP - CY	−		− −	− − −								
GDP - NY	−		− − −							− −		
Consumption - CY				− −		− −						− − −
Consumption - NY		− −						−	+	− − −		
Oil - 3M												
Oil - 1Y					+							

Notes: This table reports the sign and significance of the estimated β parameter for different model specifications. Each row corresponds to a set of specifications where the forecasted variable and the forecast horizon are identical. The forecast horizons are abbreviated as follows: 3M = 3 month, 1Y = 1 year, CY = current year, NY = next year. Each column corresponds to a set of specifications where the transparency is captured by the same index or sub-index and the forecast is characterized either by the absolute forecast error of the consensus forecast (ABSFE) or by the standard deviation of the individual forecasts (STDEV). −, − −, and − − − indicate negative estimates at the 10 percent, 5 percent, and 1 percent significance levels, respectively. +, ++, and +++ indicate positive estimates at the 10 percent, 5 percent, and 1 percent significance levels, respectively. Empty cells correspond to insignificant estimates.

In contrast to our benchmark estimates obtained with our static model (1) on non-overlapping observations, the benchmark estimates of Ehrmann, Eijffinger, and Fratzscher (2010) and Ehrmann, Eijffinger, and Fratzscher (2012) obtained with their dynamic model on forecasts with overlapping forecast horizons are biased. We can even detect the bias empirically by the oil price regressions when the quality of forecasts is measured by the forecast accuracy. See table 3, which summarizes the results on the main parameter of our interest, β.[16]

The *theoretical reason for the presence of bias* is that their model is a dynamic model with country fixed effects and the LSDV estimator provides consistent but biased estimates in this case (see Judson and Owen 1997). In addition, if the forecast horizons of the consecutive monthly observations are overlapping, as in Ehrmann, Eijffinger, and Fratzscher (2010) and also in Ehrmann, Eijffinger, and Fratzscher (2012),[17] then the error term $\epsilon_{i,t}$ becomes autocorrelated and it results in biased standard error estimates and invalidates the standard t-test (see Hansen and Hodrick 1980; Harri and Brorsen 2009).[18]

Both of the above issues and the empirical evidence on the presence of bias support our strategy to deviate from the approach of Ehrmann, Eijffinger, and Fratzscher (2010) and Ehrmann, Eijffinger, and Fratzscher (2012) by estimating a static model on non-overlapping observations.[19]

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[16]The details of the regression results can be found in the upper part of tables 26 and 27 in Csavas et al. (2012).

[17]The benchmark estimates of Ehrmann, Eijffinger, and Fratzscher (2012) are obtained in the very same way as those of Ehrmann, Eijffinger, and Fratzscher (2010), with the minor difference that fiscal transparency is also controlled for in the former. Obviously, this difference does not correct for the bias in the parameter estimates and in the standard error estimates. Another difference between Ehrmann, Eijffinger, and Fratzscher (2012) and Ehrmann, Eijffinger, and Fratzscher (2010) is that the former does not report estimates for the forecast accuracy, only for the dispersion of forecasts. Their results with the dispersion of forecasts are more reliable, as we find evidence for the presence of bias by the oil price regressions only when the dependent variable is the forecast accuracy.

[18]Csavas et al. (2012) mistakenly attributed biased parameter estimates to the overlapping nature of the data, while only bias in standard error estimates should be attributed to it.

[19]In the static model we do not control for potential persistency in the dependent variable. However, it is not necessary, because the coefficient of the lagged dependent variable in the dynamic model is no more significant when the estimation is carried out on the non-overlapping sample.

Table 3. Sign and Significance of the Estimated Effect of Transparency on the Quality of Oil Price Forecasts: Summary of 24 Regressions with Different Model Specifications (sample: Jan. 1998–Dec. 2009, 26 countries, overlapping forecast horizons, monthly data frequency)

Transparency Index →	Political		Economic		Procedural		Policy		Operational		Total	
	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE
Oil - 3M												
Oil - 1Y		+		+		++		++		+		++

Notes: This table reports the sign and significance of the estimated β parameter for different model specifications. Each row corresponds to a set of specifications where the forecasted variable and the forecast horizon are identical. The forecast horizons are abbreviated as follows: 3M = 3 month, 1Y=1 year. Each column corresponds to a set of specifications where the transparency is captured by the same index or sub-index and the forecast is characterized either by the absolute forecast error of the consensus forecast (ABSFE) or by the standard deviation of the individual forecasts (STDEV). –, – –, and – – – indicate negative estimates at the 10 percent, 5 percent, and 1 percent significance levels, respectively. +, ++, and +++ indicate positive estimates at the 10 percent, 5 percent, and 1 percent significance levels, respectively. Empty cells correspond to insignificant estimates. The estimated model is the dynamic model in Ehrmann, Eijffinger, and Fratzscher (2010): $y_t = \beta x_{i,t} + \alpha_i + \gamma_1 \sigma_t + \gamma_2 |\Delta oil_{t-1}| + \gamma_3 y_{t-1} + \epsilon_{i,t}$, where y_t is either the absolute forecast error of the consensus forecast on the three-month-ahead oil price, the absolute forecast error of the consensus forecast on the one-year-ahead oil price, the standard deviation of the individual forecasts on the three-month-ahead oil price, or the standard deviation of the individual forecasts on the one-year-ahead oil price.

Next, we interpret the results for the forecasted macro variables. In the first ten rows in table 2, there is at least one minus sign in each column. It means that each of the five sub-indices has a significant negative coefficient in at least one model specification. If these estimates reflect causal relationship, then the interpretation of this finding is that each aspect of transparency can mitigate the uncertainty concerning at least one macro variable.

By comparing the number of minus signs in the first ten rows of table 2 *across columns*, we get an impression of which dimension of transparency matters the most for the quality of forecasts of the macro variables. The favorable effect of transparency is most robust in case of the *economic aspect of transparency*, as the economic sub-index is estimated to have a significant negative coefficient in eleven specifications out of twenty. The effect of economic transparency is significant not only statistically but also in economic terms. Let us suppose that the sub-index of economic transparency increases by one. It can be achieved by the central bank, for instance, by starting to publish its macroeconomic model used for policy decisions. Our estimates suggest that this measure decreases the standard deviation of the individual forecasts on the three-month-ahead short rate by 0.02 percent (2 basis points), provided everything else remains unchanged. See the first panel (upper left) in table 11. Though this effect is small, it is not negligible in relative terms, because the sample average of the standard deviation of the individual three-month-ahead short rate forecasts is 0.23 percent.

The comparison of the results across sub-indices also sheds light on the *mechanism* that transparency presumably exerts on predictions. Central banks can have both direct and indirect impact on the private sector's forecasts. An example for the *indirect channel* is the following. Suppose the central bank enhances its transparency by prioritizing its objectives, thereby making it easier for the public to predict how it will respond to shocks in order to meet its objectives. Owing to better policy rate forecasts, macroeconomic variables become easier to forecast as well, provided that market participants understand the transmission mechanism well. In contrast to the indirect channel, the *direct channel* operates by giving the opportunity to private forecasters to simply copy the forecasts of the central bank.

Our estimates cannot determine with certainty whether the direct channel or the indirect one is at work. However, the direct channel seems to be more dominant, as economic transparency has the most robust favorable effect out of the five dimensions. Just to recall, the economic sub-index indicates whether the central bank publishes its own forecasts. If transparency affected the macroeconomic variables mostly indirectly, via better understanding of monetary policy decisions, we would see more coefficients with a significantly negative sign for the sub-indices other than the economic sub-index.

In general, we find no strong evidence against the null that higher transparency is associated with better forecasts. Our one-sided test rejects the null $\beta < 0$ at the 10 percent significance level only four times out of 120 specifications presented in the first ten rows of table 2. Given that the corresponding probability of the type I error is 10 percent, the expected number of rejections is twelve out of every 120 independent estimations. However, our 120 estimates are not independent for a number of reasons. By counting only those estimates among which there is no trivial linear dependence, we get twenty as a product of five (number of roughly independent sub-indices), four (number of roughly independent macro variables, the two real variables count as one), one (the two forecast horizons count as one), and one (number of independent measures on the quality of forecasts). As we obtain only four rejections out of twenty independent estimates, we do not have strong evidence against the hypothesis $\beta < 0$, even if we take into account the dependence between regressions. The picture is even better if we consider that the four rejections are not independent either: out of the four rejections, two fall to those twenty independent estimates where the quality of forecasts is measured by the forecast accuracy, while the other two rejections fall to those other twenty independent estimates where the quality of forecasts is measured by the dispersion of forecasts. Hence, the ratio of the number of independent rejections to the number of independent estimates is 10 percent.

Table 2 also reveals which macro forecast correlates with most of the dimensions of transparency. It is the *short-term interest rate* that can be forecasted with either significantly higher precision or significantly less disagreement or both, if the central bank improves on the political, economic, or operational aspect of transparency.

This finding is not surprising, because the short rate is the variable most closely related to monetary policymaking and communication, as the policy instrument itself is a specific short-term rate at many central banks. Regarding the forecasts on the other two nominal variables, the *ten-year interest rate* and the *inflation rate*, much fewer estimates are significant. This finding reflects that central banks are able to affect these variables only indirectly. The effect of monetary policy on *real variables* is even less direct than that on the long rate and inflation rate, as they are less tightly connected to the policy instrument through the monetary transmission mechanism.[20] Finding a significant relationship between central bank transparency and *GDP* or *consumption* forecasts could be interpreted as *indirect evidence for the effectiveness of monetary policy* that is often debated in the literature. An alternative interpretation attributes the significant relationship to the *direct channel* functioning through publishing central bank forecast on real variables. This alternative interpretation seems to be more plausible, as a significant favorable impact of transparency on real variables is found mostly in those specifications where transparency is measured by the economic sub-index. It is worth mentioning that the economic sub-index of transparency, more precisely its 2C component, indicates whether the central bank publishes forecasts, but the published forecasts should not necessarily be on real variables. In order to obtain a clearer view on the relevance of the second interpretation, one needs to use detailed data on what variables are forecasted by central banks.

4.2 Robustness Analysis

This section provides some robustness checks on the benchmark results. We investigate whether our estimates are sensitive to changes in model specification and sample.[21]

[20]This finding is in line with Dovern, Fritsche, and Slacalek (2012), who investigate the determinants of dispersion across forecasters using the Consensus Economics data set. They show that the degree of disagreement about nominal variables (inflation and interest rate) is affected more significantly by central bank independence than the degree of disagreement about real variables (GDP, consumption, investment, and unemployment).

[21]A number of further robustness checks can be found in Csavas et al. (2012).

Whether *lengthening the sample* by the period preceding 1998 has any effect on the results is investigated by comparing our benchmark estimates summarized by table 2 with the alternative estimates summarized by table 4.[22] It is apparent that the estimates for β are significantly negative in many more specifications when estimation is carried out on the longer sample, and the hypothesis of $\beta < 0$ cannot be rejected in any of the specifications.

When reestimating equation (1) on a restricted sample covering only the twelve *advanced countries*, we obtain similar qualitative results to those obtained on the broader sample (see table 5). The number of significantly positive and negative estimates is more or less the same as in the benchmark case.[23]

The above two sensitivity analyses are relevant for comparing our benchmark estimates with those of Ehrmann, Eijffinger, and Fratzscher (2012). Ehrmann, Eijffinger, and Fratzscher (2012) estimate their benchmark model on the sample of the twelve advanced economies, and their sample period spans between January 1990 and December 2008. As we see, choosing the sample as Ehrmann, Eijffinger, and Fratzscher (2012) do makes the hypothesis $\beta < 0$ harder to reject, and the estimates for β are significantly negative in many more specifications.

We also test whether our findings are robust to an *alternative measure of transparency*. For this exercise, we use the Minegishi and Cournède (2009) index, which quantifies the degree of transparency differently from the popular Eijffinger-Geraats index.[24] Our standard regressions confirm that a higher Minegishi-Cournède

[22]The details of the regression results in the sensitivity analyses can be found in Csavas et al. (2012). For instance, tables 30, 31, 32, 33, 46, and 47 in Csavas et al. (2012) present those results that are summarized by tables 4, 5, and 6 in this paper.

[23]One of the most puzzling results in table 5 is that political transparency increases the dispersion of inflation forecasts significantly. However, this result is not robust: when Norway is excluded from the sample, the coefficient in question is no longer significant. This sensitivity of the estimates is in line with the finding of Cecchetti and Hakkio (2009), who document that the adoption of inflation targeting by the central bank of Norway was associated with a rise in the standard deviation of inflation forecasts.

[24]The sample of Minegishi and Cournède (2009) covers the period between 1999 and 2009. It consists of eleven OECD countries, out of which eight overlap with our sample of twenty-six countries. The eight countries that are common in the samples are Canada, Germany (representing the euro zone), Japan, Norway, Sweden, Switzerland, the United Kingdom, and the United States.

Table 4. Sign and Significance of the Estimated Effect of Transparency on the Quality of Forecasts: Summary of 120 Regressions with Different Specifications of the Benchmark Model (1), Longer Sample Period (sample: Oct. 1989–Dec. 2009, 26 countries, non-overlapping forecast horizons)

Transparency Index →	**Political**		**Economic**		**Procedural**		**Policy**		**Operational**		**Total**	
	STDEV	**ABSFE**	**STDEV**	**ABSFE**	**STDEV**	**ABSFE**	**STDEV**	**ABSFE**	**STDEV**	**ABSFE**	**STDEV**	**ABSFE**
Short Rate - 3M	– – –	– –	– – –	– – –			–	–	– – –	– – –	– – –	– – –
Short Rate - 1Y	–		– – –						–		– – –	
Long Rate - 3M				– –					–			–
Long Rate - 1Y			– – –	– – –			– –		– – –		– – –	– –
CPI - CY			– – –	– –			– –	–			– – –	–
CPI - NY			– – –				– –				– – –	
GDP - CY	– – –		– – –	– – –					– – –		– – –	–
GDP - NY	– – –		– – –				–				– – –	
Consumption - CY				– – –	– –	– –						– – –
Consumption - NY		– –	– –							– – –		

Note: See notes for table 2.

Table 5. Sign and Significance of the Estimated Effect of Transparency on the Quality of Forecasts: Summary of 120 Regressions with Different Specifications of the Benchmark Model (1) (sample: Jan. 1998–Dec. 2009, 12 advanced countries, non-overlapping forecast horizons)

Transparency Index →	**Political**		**Economic**		**Procedural**		**Policy**		**Operational**		**Total**	
	STDEV	**ABSFE**	**STDEV**	**ABSFE**	**STDEV**	**ABSFE**	**STDEV**	**ABSFE**	**STDEV**	**ABSFE**	**STDEV**	**ABSFE**
Short Rate - 3M	− − −	− −		− −					− −	− − −		− −
Short Rate - 1Y	− −											
Long Rate - 3M												
Long Rate - 1Y			− −	−					− −			
CPI - CY	++			−								
CPI - NY		++	− − −			+++	− −	+			− −	+
GDP - CY	− −	−		− − −				−	− −	− − −	− −	− − −
GDP - NY	− − −		− − −			++	− − −				− − −	
Consumption - CY		− − −						−		−		−
Consumption - NY			− − −								− −	

Note: See notes for table 2.

transparency index is associated with significantly lower dispersion of forecasts and higher forecast accuracy in general (see table 6). Interestingly, the most robust results are obtained when transparency is measured either by the policy objective sub-index or by the economic analysis sub-index. These sub-indices essentially correspond to the political and economic sub-indices of the Eijffinger-Geraats index, respectively.[25] In the benchmark estimations obtained with the sub-indices of the Eijffinger-Geraats index, the political aspect of transparency has not been found to be as important as the economic aspect. Another interesting difference between the estimates obtained with the Minegishi-Cournède index and those obtained with the Eijffinger-Geraats index is that in the latter case, the most robust impact of enhanced transparency is found on the short rate forecasts out of the investigated forecasted variables. If we measure the degree of transparency by the Minegishi-Cournède index, then it is the GDP forecast upon which most of the dimensions of transparency have significant favorable effect. The two findings above contribute to our previous view on two related issues already touched upon in this paper: first, whether the forecasts are effected through the direct channel or the indirect one, and second, whether monetary policy is effective. The results obtained with the Minegishi-Cournède indices point toward the functioning of the indirect channel and provide indirect evidence for the effectiveness of monetary policy.

4.3 Testing for Causality

In this section, we apply Granger causality tests in order to see whether a higher degree of transparency contributes to better forecasts.

For the test we estimate the following two equations for each of the twelve advanced economies on data of monthly frequency:[26]

[25]The sub-indices of policy objective, economic analysis, decision-making process, and policy decision in the Minegishi-Cournède index correspond the most to the political, economic, procedural, and policy sub-indices in the Eijffinger-Geraats index, respectively.

[26]In constructing the monthly time series of the transparency indices for the advanced economies, the supplementary data appendix of Eijffinger and Geraats (2004) and the notes written to the data set of Siklos (2011) (available at http://www.central-bank-communication.net/links/) were a great help. Unfortunately, there is no similar detailed and comprehensive description of data on emerging countries.

Table 6. Sign and Significance of the Estimated Effect of the Minegishi-Cournède Transparency Index and Sub-Indices on the Quality of Forecasts: Summary of 100 Regressions with Different Specifications of the Benchmark Model (1) (sample: Jan. 1999–Dec. 2009, 8 OECD countries, non-overlapping forecast horizons)

Transparency Index →	Political Objective		Policy Decision		Economic Analysis		Decision-Making Process		Total	
	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE	STDEV	ABSFE
Short Rate - 3M	− − −	−				− −				− −
Short Rate - 1Y					− −				−	
Long Rate - 3M										
Long Rate - 1Y										
CPI - CY							++			
CPI - NY		+	− −		− −			++		
GDP - CY	− −	− −	− −	− −	− − −		− −		− − −	−
GDP - NY	− − −									
Consumption - CY		− − −		− −				− −		− − −
Consumption - NY	− − −			− −						

Note: See notes for table 2.

$$y_{i,t} = \beta_{y,i} x_{i,t-1} + \gamma_{1,y,i} \sigma_{i,t} + \gamma_{2,y,i} \left|\Delta \text{oil}_{t-1}\right| + \gamma_{3,y,i} y_{i,t-1} + \sum_{m=1}^{11} \Theta_{i,m} I_{m,t} + \epsilon_{y,i,t}, \quad (2)$$

$$x_{i,t} = \beta_{x,i} y_{i,t-1} + \gamma_{1,x,i} \sigma_{i,t} + \gamma_{2,x,i} \left|\Delta \text{oil}_{t-1}\right| + \gamma_{3,x,i} x_{i,t-1} + \epsilon_{x,i,t}. \quad (3)$$

The notation of the variables is the same as before, with the following exceptions: $y_{i,t}$ denotes only the dispersion of forecasts (but not the forecast accuracy) at time t for country i. $I_{m,t}$ is an indicator function taking value 1 if time t is in month m and 0 otherwise. Accordingly, the term $\sum_{m=1}^{11} \Theta_{i,m} I_{m,t}$ stands for the month fixed effects. We control for the month fixed effects only for those variables that are forecast with changing forecast horizons.

Unlike the benchmark regression, we estimate equations (2) and (3) for each country separately. This deviation has the following consequences for the model, the estimation method, and the data. First, there is no need for country dummies in the regressions. Second, the estimates obtained with LSDV will be unbiased (in contrast with the LSDV estimates for the dynamic panel model with individual effects). Third, we have to work with the sample of forecasts with overlapping forecast horizons; otherwise, we would have too short time series. The overlapping nature of the data necessitates the inclusion of month fixed effects.[27]

Table 7 summarizes the results of Granger causality tests. Unfortunately, the vast majority of these tests are not conclusive on the direction of causality, either because of finding causality in both directions or because of finding it in neither of the directions. However, in those specifications and for those countries where the causality points to one definite direction, it is dominantly the one that can be exploited by central banks: it is transparency that seems to cause the quality of forecasts, and not vice versa.

[27]Fortunately, the overlapping nature of the data is less of an issue when the quality of forecasts is measured by the standard deviation of the individual forecasts as opposed to being measured by the absolute forecast errors. Csavas et al. (2012) present the results of the Granger causality tests also for the latter.

Table 7. Summary of the Granger Causality Tests between Transparency and Dispersion of Forecasts (sample: Jan. 1998–Dec. 2009, 12 advanced countries)

	Transparency Is Measured by Index or Sub-index											
	Political	**Economic**	**Procedural**	**Policy**	**Operational**	**Total**	**Political**	**Economic**	**Procedural**	**Policy**	**Operational**	**Total**
Quality of Forecast	*Standard Deviation of the Individual Three-Month-Ahead Short Rate Forecasts*						*Standard Deviation of the Individual Twelve-Month-Ahead Short Rate Forecasts*					
TR → QF	1	2	0	2	3	2	0	3	0	2	1	3
TR ← QF	1	2	0	1	0	1	0	0	0	1	0	1
TR ↔ QF	0	0	0	0	0	1	0	0	0	1	0	0
TR QF	1	7	1	6	2	8	3	8	1	5	4	8
Num. of Countries	3	11	1	9	5	12	3	11	1	9	5	12
Quality of Forecast	*Standard Deviation of the Individual Three-Month-Ahead Long Rate Forecasts*						*Standard Deviation of the Individual Twelve-Month-Ahead Long Rate Forecasts*					
TR → QF	0	1	0	1	0	2	0	3	0	1	0	3
TR ← QF	0	2	0	0	0	1	0	1	0	0	1	2
TR ↔ QF	1	1	0	0	0	2	0	0	0	0	1	0
TR QF	2	6	1	7	5	6	3	6	1	7	3	6
Num. of Countries	3	10	1	8	5	11	3	10	1	8	5	11
Quality of Forecast	*Standard Deviation of the Individual Current-Year CPI Forecasts*						*Standard Deviation of the Individual Next-Year CPI Forecasts*					
TR → QF	1	2	0	2	1	2	0	1	0	2	1	3
TR ← QF	0	1	0	0	2	1	0	0	0	0	0	0
TR ↔ QF	0	0	0	0	1	1	1	0	0	0	0	0
TR QF	2	8	1	7	1	8	2	10	1	7	4	9
Num. of Countries	3	11	1	9	5	12	3	11	1	9	5	12

(*continued*)

Table 7. (Continued)

	Transparency Is Measured by Index or Sub-index											
	Political	**Economic**	**Procedural**	**Policy**	**Operational**	**Total**	**Political**	**Economic**	**Procedural**	**Policy**	**Operational**	**Total**
Quality of Forecast	*Standard Deviation of the Individual Current-Year GDP Forecasts*						*Standard Deviation of the Individual Next-Year GDP Forecasts*					
TR → QF	0	2	0	1	0	2	0	3	0	0	0	3
TR ← QF	1	1	0	0	1	1	1	2	0	2	2	0
TR ↔ QF	0	0	0	0	0	0	0	1	0	2	0	1
TR QF	2	8	1	8	4	9	2	5	1	5	3	8
Num. of Countries	3	11	1	9	5	12	3	11	1	9	5	12
Quality of Forecast	*Standard Deviation of the Individual Current-Year Consumption Forecasts*						*Standard Deviation of the Individual Next-Year Consumption Forecasts*					
TR → QF	0	2	0	2	0	3	0	3	0	2	0	4
TR ← QF	0	0	0	0	1	0	0	0	0	2	0	0
TR ↔ QF	0	0	0	0	0	0	1	0	0	1	0	0
TR QF	3	9	1	7	4	9	2	8	1	4	5	8
Num. of Countries	3	11	1	9	5	12	3	11	1	9	5	12

Notes: This table reports the number of countries with different results of the Granger causality test. The significance level for the Granger causality tests is set to 10 percent. "TR → QF" means one-way causality, i.e., we can reject the hypothesis that transparency does not Granger-cause the quality of forecast, but we cannot reject the hypothesis that quality of forecast does not Granger-cause transparency. "TR ← QF" means one-way causality to the opposite direction. "TR ↔ QF" means two-way causality. "TR QF" means no causal relationship. "Num. of Countries" indicates the total number of countries for which we could run the causality test. Central bank transparency is measured by the Eijffinger-Geraats index on monthly frequency.

4.4 Weighted Transparency Index

Composite indices are often used in social sciences. Some of these indices are calculated as the averages or sums of *equally weighted sub-indices*, while others use various *weighting schemes.* Choosing the weights is based either on the value judgments of experts or on well-documented and replicable methods such as factor analysis or regressions.

In this section we use the *regression method* to construct a weighted transparency index. In section 4.1, we already identified the important sub-indices of transparency through their effects on uncertainty. Here, we apply a similar approach in order to assign weights to each of the fifteen components of the Eijffinger-Geraats index. The weights are chosen so that the resulting composite index explains the maximum variation in the dependent variable. The method is demonstrated on the standard deviation of the individual current-year consumer price index forecasts as the dependent variable, because this forecast is available for all countries in our sample.[28]

First, we run our workhorse regression (1) with the explanatory variable $x_{i,t}$ being one of the components and the dependent variable $y_{i,t}$ being the standard deviation of the individual CPI forecasts. The coefficient of each of the fifteen components is estimated to be negative whenever it is significant (see table 8).

Second, we assign weights to the components by estimating model (4).

$$y_{i,t} = \beta \sum_{j=1}^{15} \lambda_j x_{i,t,j} + \alpha_i + \gamma_1 \sigma_{i,t} + \gamma_2 \left|\Delta \text{oil}_{t-1}\right| + \eta_{i,t},$$

$$\text{where} \sum_{j=1}^{15} \lambda_j = 1 \tag{4}$$

[28]However, the method can be applied to alternative dependent variables as well, resulting in different weighting schemes. Csavas et al. (2012) demonstrates the method of estimating weights on the standard deviation of the individual short rate forecasts as the dependent variable. Unfortunately, these forecasts are available for far fewer countries than the CPI forecasts.

Table 8. Components of the Central Bank Transparency Index and the Dispersion of Individual Current-Year CPI Forecasts: Benchmark Model (sample: Jan. 1998–Jan. 2009, 26 countries, non-overlapping forecast horizons)

	Transparency Is Measured by One of the Components														
	Political			Economic			Procedural			Policy			Operational		
	Formal Objectives	Quantitative Targets	Institutional Arrangements	Economic Data	Policy Models	Central Bank Forecast	Explicit Strategy	Minutes	Voting Records	Prompt Announcement	Policy Explanation	Policy Inclination	Control Errors	Transmission Disturbances	Evaluation of Policy Outcomes
	1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C
Dependent Variable	*Standard Deviation of the Individual Current-Year CPI Forecasts*														
Transparency	−0.08	−0.13	−0.21	−0.34	−0.08	−0.26***	−0.6***	−0.01	0.05	−0.65**	−0.14	0	−0.02	−0.08	0.13
(t-stat)	(−1.02)	(−0.62)	(−1.23)	(−1.2)	(−1.62)	(−2.83)	(−7.71)	(−0.14)	(0.96)	(−2.05)	(−1.04)	(−0.07)	(−0.2)	(−1.27)	(0.72)
Cond. Volatility	0.11	0.11	0.11	0.11	0.12	0.12	0.11	0.11	0.11	0.1	0.12	0.11	0.11	0.11	0.11
(t-stat)	(1.46)	(1.48)	(1.47)	(1.46)	(1.51)	(1.63)	(1.47)	(1.45)	(1.44)	(1.27)	(1.51)	(1.45)	(1.46)	(1.45)	(1.45)
$\|\Delta oil_{t-1}\|$	0.02***	0.02***	0.02***	0.02***	0.02***	0.03***	0.02***	0.02***	0.02***	0.02***	0.02***	0.02***	0.02***	0.02***	0.02***
(t-stat)	(4.8)	(4.25)	(4.99)	(4.48)	(4.8)	(5.86)	(4.66)	(4.72)	(4.79)	(4.89)	(4.26)	(4.86)	(4.37)	(4.99)	(4.9)
Number of Obs.	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210
R^2	75.94%	76.02%	76.02%	76.13%	76.20%	78.04%	76.59%	75.92%	75.95%	76.64%	76.16%	75.92%	75.92%	75.95%	75.94%

Note: To save space, the regression coefficients for the country fixed effects are not reported.

The explanatory variable $x_{i,t,j}$ denotes the jth component of the transparency index in country i at time t and λ_j is its weight. The weighted transparency index is then $\sum_{j=1}^{15} \lambda_j x_{i,t,j}$. In this model, β captures the effect of the weighted transparency index on the quality of forecasts. $\eta_{i,t}$ is a Gaussian error term. The notation of all the other variables is the same as before.

It is worth noting that we do not rule out a priori to obtain negative weights. This is a principal difference relative to the equally weighted Eijffinger-Geraats index. Negative weights correspond to the case when higher transparency is associated with higher forecast dispersion, provided $\beta < 0$. Tables 2–6 suggest that estimating negative weights does not only have a theoretical possibility.

Once model (4) is estimated, we test the hypothesis $\lambda_j = \lambda$ for all $j \in \{1..15\}$. The standard F-test rejects the equality of the weights at any meaningful significance level; therefore, a weighted index may better reflect the actual degree of central bank transparency than the equally weighted one.

Table 9 reports the estimated weights λ_j and the estimates on the coefficient of the weighted transparency index ($\widehat{\beta} = -1.78$). The latter is significantly negative as is in line with our intuition, suggesting that the higher the weighted transparency index, the lower the degree of disagreement. There are three components to which high and significantly positive weights are assigned. These are "central bank forecasts" (2C), "explicit strategy" (3A), and "prompt announcement" (4A). The rest of the components have either negative weights or positive but insignificant weights. The lack of significance and the negative sign of these weights might reflect either that the components in question do not influence uncertainty in the economy substantially, or that they take non-zero values for too few countries and too short of a period to identify their effects by the regressions,[29] or that these components are highly correlated with some others. High correlation can not only make the standard errors high, but can also result in negative weights of some components

[29]For instance, the component for policy inclination (4C) takes a non-zero value only for the Riksbank from 2002 on and for the Federal Reserve from 1999 on in our sample. Although our intuition suggests that official policy inclination is a great help for the private forecasters, its estimated coefficient is insignificant.

Table 9. Estimated Weights of the Weighted Transparency Index (sample: Jan. 1998–Jan. 2009, 26 countries, non-overlapping forecast horizons)

	Relative Weights	t-stat
1A. Formal Objectives	−0.036	(−0.47)
1B. Quantitative Targets	0.151	(1.11)
1C. Institutional Arrangements	0.092	(0.94)
1. Political Transparency	0.207	
2A. Economic Data	0.104	(1.33)
2B. Policy Models	−0.037	(−0.89)
2C. Central Bank Forecast	0.23***	(3.06)
2. Economic Transparency	0.297	
3A. Explicit Strategy	0.31***	(4.47)
3B. Minutes	−0.003	(−0.05)
3C. Voting Records	−0.025	(−0.51)
3. Procedural Transparency	0.282	
4A. Prompt Announcement	0.41***	(3.77)
4B. Policy Explanation	−0.16*	(−1.84)
4C. Policy Inclination	0.093	(1.45)
4. Policy Transparency	0.343	
5A. Control Errors	−0.075	(−0.53)
5B. Transmission Disturbances	0.015	(0.19)
5C. Evaluation of Policy Outcomes	−0.07	(−0.34)
5. Operational Transparency	−0.13	
Weighted Transparency	−1.78***	(−5.21)
Number of Obs.	210	
R^2	80.34%	

Notes: This table reports the λ_j weights and the β coefficient of the weighted index in equation (4). The dependent variable is the standard deviation of the individual current-year CPI forecasts. The weight assigned to each of the sub-indices is calculated as the sum of weights of its components.

whose role is partly taken over by a correlating component. This phenomenon is called *multicollinearity*. Although multicollinearity can lead to coefficient estimates with counterintuitive signs in some instances, it is likely to affect neither the ranking of the countries nor the aggregate transparency index we propose, as the sum of scores assigned to a group of highly correlating sub-indices reflects the degree of the given aspects of transparency correctly.

Whether some components are assigned to significantly positive weights only because of being correlated with some other important aspects of transparency can be checked by looking at their unconditional effects on uncertainty. Among the three components with significantly positive weights, each is found to have a favorable impact, even in those specifications where no other aspects of transparency are controlled for, as is reported by table 8. Based on this finding, central banks are advised to (i) prepare and publish their own forecasts, (ii) provide an explicit policy rule or strategy that describes the monetary policy framework, and (iii) promptly announce policy decisions.

The estimated weighting scheme allows us to calculate the weighted composite transparency index characterizing each central bank for which the Eijffinger-Geraats index is available. In addition, we can rank these central banks based upon the weighted index. Table 10 reports two rankings: one is based on the Eijffinger-Geraats index, and the other is based on the weighted index. When comparing these rankings, we find some similarities and differences as well. The Spearman rank-order correlation is 0.85 between the two rankings. Out of ninety-seven central banks, there are thirty-seven whose relative position in the Eijffinger-Geraats ranking is out of the 90 percent confidence interval of our ranking.

5. Conclusions

Whether enhanced central bank transparency is favorable is not evident from the literature. For instance, Morris and Shin (2002) argue as follows. If central banks have only noisy information on the future evolution of some variables, and their noisy information is less precise than that of the market, then achieving a higher

Table 10. Country Rankings Based on the Degree of Transparency of Their Central Banks in 2009

	Eijffinger-Geraats Index		Weighted Index			
					Percentile of the Ranking	
Country Name	**Score**	**Ranking**	**Score**	**Ranking**	**5th**	**95th**
Albania	9.0	17	0.94	23	11	34
Argentina	7.5	26	0.61	46	22	76
Armenia	8.0	21	0.77	36	19	54
Aruba	0.5	97	0.05	88	82	95
Australia	10.5	8	0.87	31	19	38
Bahamas	4.5	58	0.51	57	44	71
Bahrain	5.0	51	0.56	52	41	63
Bangladesh	3.5	66	0.25	79	69	84
Barbados	4.0	61	0.58	50	39	69
Belarus	5.0	51	0.58	49	40	63
Belize	3.0	69	0.42	66	46	83
Bermuda	1.0	92	0.03	89	85	91
Bhutan	3.0	69	0.41	68	54	78
Brazil	9.0	17	1.23	1	1	6
Bulgaria	5.5	44	0.54	54	38	71
Canada	11.0	6	0.96	18	10	30
Chile	7.5	26	0.96	20	7	35
China	4.5	58	0.43	63	49	77
Colombia	7.5	26	1.12	3	3	12
Croatia	6.0	39	0.43	64	38	81
Cuba	2.5	76	0.38	73	59	76
Czech Rep.	11.5	4	1.00	14	3	32
Denmark	7.5	26	0.81	34	23	45
East Caribbean	7.0	30	0.67	43	22	66
Egypt	3.0	69	0.26	77	53	95
El Salvador	3.0	69	0.28	76	51	91
EMU	11.0	6	0.96	18	10	30
Estonia	6.0	39	0.76	38	17	52
Ethiopia	1.0	92	0.03	89	85	91
Fiji	4.0	61	0.74	39	26	56
Georgia	5.5	44	1.04	8	1	36
Ghana	5.5	44	0.67	42	38	57
Guatemala	5.5	44	0.63	45	30	66
Guyana	1.5	89	0.01	95	84	96
Hong Kong	7.0	30	0.39	71	54	79
Hungary	11.5	4	1.00	16	5	30
Iceland	8.5	20	1.10	5	1	23

(*continued*)

Table 10. (Continued)

	Eijffinger-Geraats Index		Weighted Index			
					Percentile of the Ranking	
Country Name	**Score**	**Ranking**	**Score**	**Ranking**	**5th**	**95th**
India	2.0	84	0.11	86	75	94
Indonesia	8.0	21	1.03	9	5	22
Iraq	2.5	76	0.38	73	59	76
Israel	9.5	12	0.88	30	19	37
Jamaica	6.5	37	1.06	7	1	29
Japan	10.0	9	0.38	75	46	84
Jordan	2.0	84	0.44	62	48	76
Kazakhstan	5.5	44	0.90	27	8	41
Kenya	5.0	51	0.54	55	43	68
Korea	9.0	17	0.91	26	16	35
Kyrgyzstan	5.0	51	0.53	56	41	71
Kuwait	2.0	84	0.18	82	65	93
Latvia	7.0	30	0.73	40	21	55
Lesotho	3.5	66	0.39	70	51	80
Libya	2.0	84	0.18	82	65	93
Lithuania	4.5	58	0.57	51	30	76
Malawi	2.5	76	0.39	72	49	82
Malaysia	6.0	39	0.77	37	12	61
Mauritius	5.5	44	0.90	29	14	36
Mexico	7.0	30	0.60	47	38	61
Moldova	6.0	39	0.91	25	11	36
Mongolia	6.0	39	0.55	53	41	68
Namibia	7.0	30	1.01	13	7	26
New Zealand	14.0	2	1.03	11	4	30
Nigeria	4.0	61	0.46	59	52	74
Norway	8.0	21	0.84	33	21	42
Oman	1.5	89	0.20	81	69	87
Pakistan	3.5	66	0.45	60	53	73
Papua New Guinea	5.0	51	0.42	65	45	83
Peru	8.0	21	0.90	28	14	37
Philippines	9.5	12	1.15	2	1	20
Poland	10.0	9	1.01	12	6	22
Qatar	3.0	69	0.49	58	45	74
Romania	6.5	37	0.92	24	10	36
Russia	3.0	69	0.02	94	80	97
Rwanda	2.5	76	0.16	84	63	97
Saudi Arabia	1.0	92	0.03	89	85	91

(*continued*)

Table 10. (Continued)

	Eijffinger-Geraats Index		Weighted Index			
					Percentile of the Ranking	
Country Name	**Score**	**Ranking**	**Score**	**Ranking**	**5th**	**95th**
Sierra Leone	1.0	92	0.03	89	85	91
Singapore	7.0	30	0.87	32	9	46
Solomon Islands	2.0	84	0.11	86	75	94
South Africa	9.5	12	0.94	22	3	41
Sri Lanka	7.0	30	0.96	21	12	28
Sudan	2.5	76	0.15	85	76	95
Sweden	15.0	1	1.00	15	4	31
Switzerland	9.5	12	1.03	10	2	36
Tajikistan	2.5	76	0.01	97	79	97
Tanzania	5.0	51	0.44	61	55	73
Thailand	8.0	21	1.10	4	2	14
Trinidad and Tobago	5.5	44	0.78	35	24	52
Tunisia	4.0	61	0.65	44	39	61
Turkey	9.5	12	1.08	6	3	23
Uganda	2.5	76	0.25	78	53	93
Ukraine	4.0	61	0.39	69	48	83
United Arab Emirates	3.0	69	0.59	48	34	71
United Kingdom	12.5	3	0.97	17	8	31
United States	10.0	9	0.42	66	40	85
Uruguay	5.0	51	0.68	41	19	67
Vanuatu	2.5	76	0.23	80	57	94
Yemen	1.0	92	0.03	89	85	91
Zambia	1.5	89	0.01	95	84	96

Notes: This table reports two rankings of ninety-seven central banks. The weights of the weighted index are estimated on data of twenty-six countries with twenty independent central banks and are reported by table 9 (the names of the additional seventy-seven countries are typeset in italic). The 10 percent confidence band of the ranking is calculated by simulation. First, we generate 1,000 independent random vectors of weights from multivariate Gaussian distribution with expected value being the vector of point estimates of the weights and covariance being the estimated covariance matrix of the weights. Second, for each of the 1,000 vectors of weights we determine the corresponding ranking of countries and the 5th and 95th percentile of the distribution of the relative position of each country.

degree of transparency can crowd out valuable private information and increase forecast error of private agents.[30]

This paper contributes to the literature by investigating empirically whether a higher degree of central bank transparency can mitigate the uncertainty in the economy. This question is examined also by Ehrmann, Eijffinger, and Fratzscher (2010, 2012) with a similar model to ours and on data from the same source. We come to the same conclusion as they do, i.e., our regression results mostly support the view that enhancing central bank transparency is favorable. In contrast to Ehrmann, Eijffinger, and Fratzscher (2012), we show in this paper not only that a higher degree of transparency is associated with less disperse views of the private forecasters, but also that it is associated with more accurate forecasts. What makes this finding important is that becoming more transparent is definitely undesirable if it synchronizes the private forecasts, but at a lower level of accuracy.

The effect of transparency on forecast accuracy is estimated also by Ehrmann, Eijffinger, and Fratzscher (2010); however, their parameter estimates are biased due to being obtained from a dynamic panel model with individual fixed effects by the least-squares method. This paper and Csavas et al. (2012) demonstrate the presence of bias by regressions on oil price forecasts. Here, the idea is that one should not find a significant relationship between the accuracy of oil price forecasts and any measure of central bank transparency, as oil price is exogenous to monetary policy. When using the same model and estimation method as Ehrmann, Eijffinger, and Fratzscher (2010), we can falsely reject exogeneity; however, we find no significant relationship between accuracy of oil price forecasts and transparency with a more rigorous approach.

When studying the mechanism of how forecasts are affected by transparency, we obtain somewhat controversial results. When

[30]Although the result of Morris and Shin (2002) is challenged by Svensson (2006), it is underpinned by alternative theories. For instance, Kool, Middeldorp, and Rosenkranz (2011) show how greater transparency can reduce forecasting accuracy if market participants choose to refrain from investing in private information when they can get costless guidance on future rates from the central bank's public signals. Unlike Morris and Shin, this result does not rely on coordination effects and higher-order expectations or what Svensson (2006) identifies as implausible calibration of the relative precisions of the public and private signals.

transparency is measured by the Eijffinger-Geraats index, we find that the economic sub-index has the most robust favorable effect out of the five sub-indices. As the economic sub-index captures whether central banks publish their own forecasts, this finding supports the view that transparency exerts its effect dominantly through the direct channel. However, when transparency is measured by the Minegishi-Cournède index, the policy aspect of transparency turns out to be equally important as the economic aspect. This latter finding underpins the operation of the indirect channel, i.e., the uncertainty of private forecasters can be mitigated not only by directly providing the market with the predictions of the central bank but also by informing the public about the goals of the central bank and clarifying the priority of these goals.

Another contribution of this paper is that it makes an attempt to test the direction of causality between transparency and uncertainty. Unfortunately, the vast majority of our tests find causality either in both directions or neither of the directions. However, in those specifications where the Granger causality points to one definite direction, then it is dominantly the one that supports our normative perspective.

In addition, we construct a weighted index of central bank transparency. The index we propose aggregates the same fifteen components as the composite Eijffinger-Geraats index. The weights we assign to the components are established empirically and reflect the relative importance of the components in reducing uncertainty. There are three components that are assigned to high and significantly positive weights. Along these lines, the best practice of central banking involves (i) preparing and publishing own forecasts, (ii) providing an explicit policy rule or strategy that describes the monetary policy framework, and (iii) promptly announcing policy decisions.

The composite index we propose in this paper, although being a weighted index, is still subject to some criticisms. First, it is a linear function of fifteen components that do not necessarily complement each other in a linear manner. Second, there are certain aspects of central bank transparency that are captured neither by the components of the Eijffinger-Geraats index nor by our weighted composite index. Just to mention one of these aspects, it is not accounted for whether detailed information is provided on the views of the individual council members.[31] Third, while our regression method allows us to identify which aspects of transparency are effective, it does not allow us to conclude that some other newer or less employed aspects of transparency are ineffective. Our regression method might fail to recognize the importance of any type of transparency that has only been employed recently or by only a few countries. These points call for future research on measuring central bank transparency.

[31] This information can be shared by the central bank watchers by publishing attributed minutes. Attributed minutes are unique in the sense that one can learn from them not only the points raised in the council or board meetings but also who made the given point during the discussion. The advantages of providing detailed information about individual committee members' views are discussed by Svensson (2009).

Appendix

Table 11. Central Bank Transparency and Dispersion of Forecasts: Benchmark Model (sample: Jan. 1998–Dec. 2009, 26 countries, non-overlapping forecast horizons)

	Transparency Is Measured by Index or Sub-index											
	Political	**Economic**	**Procedural**	**Policy**	**Operational**	**Total**	**Political**	**Economic**	**Procedural**	**Policy**	**Operational**	**Total**
Dependent Variable	*Standard Deviation of the Individual Three-Month-Ahead Short Rate Forecasts*						*Standard Deviation of the Individual Twelve-Month-Ahead Short Rate Forecasts*					
Transparency	−0.07***	−0.02	0	−0.01	−0.05**	−0.01	−0.11*	−0.06*	−0.02	0.01	−0.05	−0.03*
(t-stat)	(−3.1)	(−1.42)	(−0.11)	(−0.44)	(−2.12)	(−1.63)	(−1.74)	(−1.69)	(−0.41)	(0.24)	(−0.78)	(−1.94)
Cond. Volatility	0.16*	0.16*	0.16*	0.16*	0.16*	0.16*	0.13	0.1	0.12	0.13	0.13	0.11
(t-stat)	(1.68)	(1.69)	(1.67)	(1.7)	(1.69)	(1.66)	(0.75)	(0.59)	(0.69)	(0.73)	(0.71)	(0.61)
$\|\Delta oil_{t-1}\|$	0	0	0	0	0	0.01	0	0.01	0	0	0	0
(t-stat)	(1.17)	(1.18)	(0.99)	(1.01)	(1.08)	(1.21)	(0.27)	(0.63)	(0.19)	(0.13)	(0.2)	(0.5)
Number of Obs.	624	624	624	624	624	624	170	170	170	170	170	170
R^2	47.8%	47.24%	46.99%	47.01%	47.21%	47.39%	54.31%	54.61%	54.05%	54.04%	54.08%	54.41%
Dependent Variable	*Standard Deviation of the Individual Three-Month-Ahead Long Rate Forecasts*						*Standard Deviation of the Individual Twelve-Month-Ahead Long Rate Forecasts*					
Transparency	0.01	0	0.06***	0.02	0.02	0	0.02	−0.02**	0	0	−0.04	−0.01
(t-stat)	(0.66)	(−0.14)	(3.07)	(1.11)	(0.94)	(0.77)	(0.72)	(−2.08)	(0.02)	(−0.03)	(−1.55)	(−0.96)
Cond. Volatility	0.6***	0.59***	0.6***	0.61***	0.6***	0.61***	1.25***	1.19***	1.24***	1.24***	1.24***	1.22***
(t-stat)	(5.61)	(5.83)	(5.44)	(5.65)	(5.58)	(5.74)	(8.07)	(8.26)	(8.01)	(8.19)	(7.84)	(8.34)
$\|\Delta oil_{t-1}\|$	0	0	0	0	0	0	0.01*	0.01**	0.01*	0.01*	0.01*	0.01**
(t-stat)	(1.08)	(1.14)	(1.01)	(0.98)	(1.07)	(0.98)	(1.69)	(2.08)	(1.72)	(1.75)	(1.92)	(1.99)
Number of Obs.	554	554	554	554	554	554	146	146	146	146	146	146
R^2	27.71%	27.63%	28.68%	27.84%	27.75%	27.78%	53.42%	53.9%	53.35%	53.35%	53.65%	53.56%
Dependent Variable	*Standard Deviation of the Individual Current-Year CPI Forecasts*						*Standard Deviation of the Individual Next-Year CPI Forecasts*					
Transparency	−0.1	−0.1**	−0.03	−0.1	−0.02	−0.05**	−0.13	−0.19***	−0.05	−0.21***	−0.06	−0.08***
(t-stat)	(−0.87)	(−2.55)	(−0.44)	(−1.4)	(−0.54)	(−2.18)	(−1.58)	(−2.77)	(−0.7)	(−2.64)	(−0.77)	(−3.98)
Cond. Volatility	0.11	0.12	0.11	0.11	0.11	0.12	0.18	0.19	0.18	0.17	0.18	0.18
(t-stat)	(1.48)	(1.59)	(1.45)	(1.5)	(1.46)	(1.57)	(1.23)	(1.34)	(1.22)	(1.23)	(1.22)	(1.29)
$\|\Delta oil_{t-1}\|$	0.02***	0.03***	0.02***	0.02***	0.02***	0.03***	0.01	0.01***	0.01	0.01	0.01	0.01**
(t-stat)	(4.37)	(5.38)	(4.38)	(4.51)	(4.64)	(4.56)	(1.07)	(3.31)	(0.97)	(1.29)	(1.02)	(2.54)
Number of Obs.	210	210	210	210	210	210	110	110	110	110	110	110
R^2	76.06%	77.14%	75.94%	76.2%	75.93%	76.71%	75.11%	76.86%	75.01%	73.54%	75.01%	76.13%

(continued)

Table 11. (Continued)

	Transparency Is Measured by Index or Sub-index											
	Political	Economic	Procedural	Policy	Operational	Total	Political	Economic	Procedural	Policy	Operational	Total
Dependent Variable	*Standard Deviation of the Individual Current-Year GDP Forecasts*						*Standard Deviation of the Individual Next-Year GDP Forecasts*					
Transparency	−0.1*	−0.05**	0.05	−0.02	−0.08	−0.02	−0.1*	−0.08***	0.04	−0.03	0	−0.03
(t-stat)	(−1.8)	(−2.25)	(0.79)	(−0.25)	(−n1.34)	(−n1.27)	(−nn1.72)	(−1.06)	(0.85)	(−0.39)	(−0.04)	(−1.31)
Cond. Volatility	0.01	0.02	0	0	0.01	0.01	0.02	0.04	0.01	0.02	0.02	0.03
(t-stat)	(0.18)	(0.45)	(0.06)	(0.15)	(0.18)	(0.33)	(0.82)	(1.28)	(0.53)	(0.64)	(0.65)	(0.89)
$\|\Delta oil_{t-1}\|$	0.03***	0.03***	0.03***	0.03***	0.03***	0.03***	0.02***	0.02***	0.02**	0.02***	0.02**	0.02***
(t-stat)	(3.34)	(3.46)	(3.25)	(3.12)	(3.3)	(3.42)	(2.75)	(3.26)	(2.54)	(2.61)	(2.44)	(3.11)
Number of Obs.	202	202	202	202	202	202	105	105	105	105	105	105
R^2	58.22%	58.61%	57.97%	57.81%	58.03%	58.24%	80.53%	81.61%	80.28%	80.25%	80.2%	80.73%
Dependent Variable	*Standard Deviation of the Individual Current-Year Consumption Forecasts*						*Standard Deviation of the Individual Next-Year Consumption Forecasts*					
Transparency	0.04	−0.02	−0.11	0.13	0.05	0	0.18	−0.01	0.12	0.24	0.1*	0.03
(t-stat)	(0.29)	(−0.7)	(−1.51)	(1.28)	(0.69)	(0.04)	(0.98)	(−0.2)	(1.08)	(1.41)	(1.71)	(1.03)
Cond. Volatility	−0.03	−0.03	−0.02	−0.03	−0.03	−0.03	−0.1	−0.11	−0.12	−0.09*	−0.11	−0.11*
(t-stat)	(−0.06)	(−0.58)	(−0.43)	(−0.59)	(−0.6)	(−0.59)	(−1.61)	(−1.5)	(−1.47)	(−1.79)	(−1.61)	(−1.68)
$\|\Delta oil_{t-1}\|$	0.02***	0.02***	0.02***	0.02***	0.02***	0.02***	0.01***	0.02***	0.01***	0.01***	0.01***	0.01***
(t-stat)	(3.12)	(2.72)	(2.99)	(2.76)	(2.98)	(2.84)	(6)	(3.59)	(3.85)	(5.28)	(3.45)	(4.82)
Number of Obs.	202	202	202	202	202	202	105	105	105	105	105	105
R^2	78.7%	78.72%	78.91%	79.09%	78.72%	78.68%	83.77%	83.32%	83.57%	84.57%	83.47%	83.68%
Dependent Variable	*Standard Deviation of the Individual Three-Month-Ahead Oil Price Forecasts*						*Standard Deviation of the Individual Twelve-Month-Ahead Oil Price Forecasts*					
Transparency	0	0	0	0	0	0	0.01	0.02	0.03*	0.04	0.02	0.01
(t-stat)	(−0.41)	(−0.06)	(1.27)	(0.17)	(0.08)	(0.07)	(0.08)	(1.29)	(1.93)	(1.28)	(1.5)	(1.43)
Cond. Volatility	0.1***	0.1***	0.1***	0.1***	0.1***	0.1***	0.34***	0.38***	0.34***	0.38***	0.34***	0.4***
(t-stat)	(2.97)	(2.85)	(3.03)	(2.95)	(2.97)	(2.87)	(4.52)	(4.78)	(4.65)	(5.22)	(4.69)	(5.28)
$\|\Delta oil_{t-1}\|$	0***	0***	0***	0***	0***	0***	0	0	0	0	0	0
(t-stat)	(3.96)	(3.89)	(3.9)	(3.85)	(3.96)	(3.81)	(0.97)	(0.11)	(1)	(0.26)	(0.87)	(−0.17)
Number of Obs.	790	790	790	790	790	790	242	242	242	242	242	242
R^2	66.56%	66.55%	66.62%	66.56%	66.55%	66.55%	79.85%	80.68%	80.26%	81.08%	79.99%	81.36%

Notes: To save space, the country fixed effects are not reported. Regressions are estimated by LSDV estimator; the standard errors are calculated by the White cross-section method that is designed to accommodate arbitrary heteroskedasticity and robust to contemporaneous correlation across countries. The data frequency of the non-overlapping sample is three months for the three-month-ahead forecasts, annual for the twelve-month-ahead forecasts and the end-of-year forecasts, and biannual for the end-of-next-year forecasts. *, **, and *** indicate significant estimates at the 10 percent, 5 percent, and 1 percent significance levels, respectively.

Table 12. Central Bank Transparency and Forecast Accuracy: Benchmark Model (sample: Jan. 1998–Dec. 2009, 26 countries, non-overlapping forecast horizons)

	Transparency Is Measured by Index or Sub-index											
	Political	Economic	Procedural	Policy	Operational	Total	Political	Economic	Procedural	Policy	Operational	Total
Dependent Variable	*Absolute Forecast Error of the Average Three-Month-Ahead Short Rate Forecasts*						*Absolute Forecast Error of the Average Twelve-Month-Ahead Short Rate Forecasts*					
Transparency	−0.19*	−0.1***	0.04	−0.11	−0.24**	−0.06***	−0.31	−0.14	−0.62	−0.14	−0.39	−0.13
(t-stat)	(−1.94)	(−2.62)	(0.4)	(−1.35)	(−2.48)	(−2.58)	(−0.84)	(−1.07)	(−1.22)	(−0.71)	(−1.08)	(−1.53)
Cond. Volatility	0.31	0.3	0.32	0.31	0.31	0.29	−0.04	−0.12	−0.18	−0.05	−0.07	−0.16
(t-stat)	(1.26)	(1.26)	(1.28)	(1.27)	(1.26)	(1.22)	(−0.12)	(−0.33)	(−0.56)	(−0.14)	(−0.17)	(−0.46)
$\|\Delta oil_{t-1}\|$	0.03	0.04	0.03	0.03	0.03	0.04	0.05	0.05*	0.05**	0.05	0.05	0.06**
(t-stat)	(1.33)	(1.44)	(1.22)	(1.31)	(1.32)	(1.44)	(1.54)	(1.69)	(1.98)	(1.63)	(1.58)	(2.04)
Number of Obs.	624	624	624	624	624	624	170	170	170	170	170	170
R^2	24.03%	24.59%	23.38%	23.63%	24%	24.55%	23.68%	23.95%	25.74%	23.46%	23.79%	24.8%
Dependent Variable	*Absolute Forecast Error of the Average Three-Month-Ahead Long Rate Forecasts*						*Absolute Forecast Error of the Average Twelve-Month-Ahead Long Rate Forecasts*					
Transparency	0	−0.04	0.04	−0.03	−0.03	−0.01	−0.08	−0.33*	−0.13	−0.39	−0.39	−0.15
(t-stat)	(0.05)	(−1.28)	(0.6)	(−0.43)	(−0.38)	(−0.74)	(−0.28)	(−1.77)	(−0.52)	(−1.35)	(−1.15)	(−1.48)
Cond. Volatility	0.84**	0.78**	0.85**	0.82**	0.84**	0.8**	0.88	0.08	0.89	0.63	0.9	0.36
(t-stat)	(2.21)	(2.02)	(2.2)	(2.2)	(2.21)	(2.15)	(0.73)	(0.07)	(0.72)	(0.54)	(0.75)	(0.32)
$\|\Delta oil_{t-1}\|$	0.01**	0.01**	0.01**	0.01**	0.01**	0.01**	−0.04**	−0.03	−0.04**	−0.04**	−0.04**	−0.03
(t-stat)	(2.18)	(2.56)	(2.17)	(2.24)	(2.24)	(2.39)	(−2.48)	(−1.46)	(−2.54)	(−2.05)	(−2.53)	(−1.47)
Number of Obs.	554	554	554	554	554	554	146	146	146	146	146	146
R^2	15.45%	16.11%	15.51%	15.53%	15.48%	15.7%	25.59%	34.24%	25.66%	28.68%	27.12%	31.67%
Dependent Variable	*Absolute Forecast Error of the Average Current-Year CPI Forecasts*						*Absolute Forecast Error of the Average Next-Year CPI Forecasts*					
Transparency	−0.23	−0.16*	0.2	−0.18	−0.08	−0.06	1.1**	0.1	0.03	0.56	1.85**	0.21
(t-stat)	(−0.96)	(−1.94)	(0.9)	(−0.89)	(−0.26)	(−0.94)	(2.08)	(0.64)	(0.08)	(0.83)	(2.56)	(1.51)
Cond. Volatility	0.38***	0.39***	0.38***	0.38***	0.38***	0.39***	0.86***	0.84***	0.84***	0.86***	0.85***	0.85***
(t-stat)	(4.4)	(4.52)	(4.39)	(4.37)	(4.44)	(4.47)	(4.05)	(4.13)	(4.32)	(3.83)	(4.47)	(3.84)
$\|\Delta oil_{t-1}\|$	0.01	0.01	0.01	0.01	0.01	0.01	−0.22	−0.21	−0.21	−0.21	−0.23*	−0.22*
(t-stat)	(0.8)	(1)	(0.41)	(0.84)	(0.69)	(0.87)	(−1.64)	(−1.55)	(−1.48)	(−1.51)	(−1.73)	(−1.67)
Number of Obs.	210	210	210	210	210	210	84	84	84	84	84	84
R^2	51.76%	52.12%	51.8%	51.79%	51.66%	51.88%	57.46%	56.74%	56.69%	57.08%	59.32%	57.38%

(*continued*)

Table 12. (Continued)

	Transparency Is Measured by Index or Sub-index											
	Political	Economic	Procedural	Policy	Operational	Total	Political	Economic	Procedural	Policy	Operational	Total
Dependent Variable	*Absolute Forecast Error of the Average Current-Year GDP Forecasts*						*Absolute Forecast Error of the Average Next-Year GDP Forecasts*					
Transparency	0.03	−0.27***	0.09	−0.2	−0.56	−0.11	−0.31	0.16	0.13	−0.37	−0.86**	−0.04
(t-stat)	(0.06)	(−3.52)	(0.32)	(−0.52)	(−1.15)	(−1.22)	(−1.61)	(0.95)	(0.38)	(−0.74)	(−2.44)	(−0.36)
Cond. Volatility	0.25**	0.31**	0.25**	0.26**	0.26**	0.29**	−0.05	−0.12	−0.07	−0.04	0.01	−0.03
(t-stat)	(2.17)	(2.38)	(2.16)	(2.16)	(2.09)	(2.27)	(−0.26)	(−0.53)	(−0.38)	(−0.24)	(0.05)	(−0.16)
$\|\Delta oil_{t-1}\|$	0.13***	0.14***	0.13***	0.13***	0.14***	0.14***	−0.09	−0.1*	−0.09*	−0.09**	−0.08	−0.09
(t-stat)	(4.45)	(4.85)	(4.15)	(4.34)	(4.62)	(5.2)	(−1.62)	(−1.7)	(−1.67)	(−2)	(−1.54)	(−1.63)
Number of Obs.	202	202	202	202	202	202	81	81	81	81	81	81
R^2	71.3%	71.73%	71.31%	71.36%	71.56%	71.55%	29.61%	29.81%	29.41%	30.1%	31.8%	29.42%
Dependent Variable	*Absolute Forecast Error of the Average Current-Year Consumption Forecasts*						*Absolute Forecast Error of the Average Next-Year Consumption Forecasts*					
Transparency	−0.31	−0.4**	−0.97**	−0.16	−0.61	−0.23***	−0.86**	0.14	−0.79	−1.12*	−1.61***	−0.2
(t-stat)	(−0.91)	(−2.4)	(−2.38)	(−0.35)	(−1.4)	(−3.41)	(−2.23)	(0.44)	(−1.45)	(−1.8)	(−4.57)	(−1.01)
Cond. Volatility	0.77**	0.8**	0.87***	0.77**	0.77**	0.8**	0.42	0.4	0.55	0.29	0.43	0.48
(t-stat)	(2.09)	(2.24)	(2.69)	(2.08)	(2.08)	(2.21)	(1.48)	(1.07)	(1.35)	(1.6)	(1.64)	(1.51)
$\|\Delta oil_{t-1}\|$	0.03	0.04	0.03	0.03	0.03	0.05*	−0.02	−0.04	−0.03	−0.03	−0.01	−0.02
(t-stat)	(1.08)	(1.62)	(1.15)	(1.03)	(1.25)	(1.8)	(−0.43)	(−0.56)	(−0.77)	(−1.2)	(−0.3)	(−0.42)
Number of Obs.	202	202	202	202	202	202	81	81	81	81	81	81
R^2	77.5%	78.11%	78.2%	77.47%	77.65%	78.17%	59.45%	58.82%	59.62%	61.04%	61.99%	59.74%
Dependent Variable	*Absolute Forecast Error of the Average Three-Month-Ahead Oil Price Forecasts*						*Absolute Forecast Error of the Average Twelve-Month-Ahead Oil Price Forecasts*					
Transparency	−0.02	−0.02	0.01	−0.03	−0.06	−0.01	−0.03	−0.03	0.03	−0.01	−0.06	−0.01
(t-stat)	(−0.77)	(−0.86)	(0.22)	(−0.64)	(−1.19)	(−0.78)	(−0.61)	(−0.58)	(0.66)	(−0.11)	(−1.05)	(−0.51)
Cond. Volatility	−0.47*	−0.49*	−0.46*	−0.47*	−0.47*	−0.49*	−0.2	−0.26	−0.18	−0.19	−0.22	−0.25
(t-stat)	(−1.67)	(−1.7)	(−1.65)	(−1.66)	(−1.7)	(−1.7)	(−0.2)	(−0.26)	(−0.18)	(−0.19)	(−0.22)	(−0.24)
$\|\Delta oil_{t-1}\|$	0.03**	0.03**	0.03**	0.03**	0.03**	0.03**	0	0	−0.01	0	0	0
(t-stat)	(2.5)	(2.51)	(2.48)	(2.48)	(2.55)	(2.49)	(−0.1)	(−0.02)	(−0.13)	(−0.11)	(−0.08)	(−0.04)
Number of Obs.	790	790	790	790	790	790	242	242	242	242	242	242
R^2	34.8%	35.22%	34.69%	34.87%	35.06%	35.23%	6.28%	6.5%	6.27%	6.19%	6.46%	6.4%

Notes: To save space, the country fixed effects are not reported. Regressions are estimated by LSDV estimator; the standard errors are calculated by the White cross-section method that is designed to accommodate arbitrary heteroskedasticity and robust to contemporaneous correlation across countries. The data frequency of the non-overlapping sample is three months for the three-month-ahead forecasts, annual for the twelve-month-ahead forecasts and the end-of-year forecasts, and biannual for the end-of-next-year forecasts. *, **, and *** indicate significant estimates at the 10 percent, 5 percent, and 1 percent significance levels, respectively.

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Bank Lending in Times of Large Bank Reserves*

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Reserves held by the U.S. banking system rose from under \$50 billion before 2008 to \$2.8 trillion by 2014. Some economists argue that such a large quantity of reserves could lead to overly expansive bank lending as the economy recovers, regardless of the Federal Reserve's interest rate policy. In contrast, we show that the amount of bank reserves has no effect on bank lending in a frictionless model of the current banking system, in which interest is paid on reserves and there are no binding reserve requirements. Moreover, we find that with balance sheet costs, large reserve balances may instead be contractionary.

JEL Codes: G21, E42, E43, E51.

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1. Introduction

The amount of reserves held by the U.S. banking system rose from under $50 billion before 2008 to $2.8 trillion by 2014. This significant increase is important because some economists and financial market participants claim that large levels of bank reserves will lead to overly expansive bank lending.[1] Despite such concerns, little formal analysis has been conducted to show such an effect under the current banking system. In contrast, other commentators on the economy claim that the large level of reserves held in the banking system is evidence of a lack of bank lending.

In this paper, we present a basic model of the current U.S. banking system, in which interest is paid on bank reserves and there are no binding reserve requirements. We find that, absent any frictions, lending is unaffected by the amount of reserves in the banking system. The key determinant of bank lending is the difference between the return on loans and the opportunity cost of making a loan. We show that this difference does not depend on the quantity of reserves. Moreover, when we introduce frictions, in the form of a cost related to the size of a bank's balance sheet, increases in reserves may actually reduce bank lending and lead to a decrease in prices.

The current banking system in the United States and worldwide no longer resembles the traditional textbook model of fractional reserve banking. Historically, the quantity of reserves supplied by a central bank determines the amount of bank loans. Through the "money multiplier," banks expand loans to equal the amount of reserves divided by the reserve requirement. However, in many countries, reserve requirements have been reduced either to zero or to such small levels that they are no longer binding.[2]

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[1] In speeches, former Federal Reserve Bank of Philadelphia President Charles Plosser expressed concern about the eventual need "to restrain the huge volume of excess reserves from flowing out of the banking system" (Plosser 2011), and former Federal Reserve Bank of Dallas President Richard Fisher cautioned about "excess reserves waiting to be converted to bank loans" (Fisher 2009). Meltzer (2010) expresses similar concerns.

[2] Bennett and Peristiani (2002) show that reserve requirements have been largely avoided in the United States since the 1980s by sweep accounts, and that the remaining reserve requirements are largely met by vault cash that banks hold

Starting in the late 1980s, the Federal Reserve supplied the quantity of reserves needed to maintain its policy target—the federal funds rate—which is the interest rate at which banks lend reserves to each other in the interbank market. The Federal Reserve did not target the amount of reserves, the quantity of deposits or loans on banks' balance sheets, or broad measures of the money supply. In that regime, the federal funds rate represents a bank's alternative return on assets and hence is the required marginal return on bank lending. Banks expand their balance sheets so long as the marginal cost of funding is less than the marginal return on bank lending, abstracting from credit and liquidity risk. The federal funds rate sets the level of the required marginal return.

From 2007 through 2014, the Federal Reserve greatly expanded the scope of its tools to address the financial crisis and a severe recession. Bank reserves increased rapidly during the financial crisis as the Federal Reserve provided unprecedented unsterilized lending through several facilities after the bankruptcy of Lehman Brothers. Reserves increased much further during the weak economic recovery as the Federal Reserve purchased Treasury securities, agency mortgage-backed securities, and agency debt as part of the large-scale asset purchases (LSAPs), also known as "quantitative easing," or "QE." Altogether, between September 2008 and mid-2014, bank reserves grew from under $50 billion to $2.8 trillion, as illustrated in figure 1. To allow the Federal Reserve to continue targeting its policy rate even with large reserves outstanding, Congress accelerated previously granted authority for the Federal Reserve to pay interest on reserves in the Emergency Economic Stabilization Act of 2008. The Federal Reserve began paying interest on reserves on October 9, 2008. Paying interest on reserves allows the Federal Reserve to choose the required return on banks' reserves independent of the quantity of reserves in the banking system.[3]

at branches and automated teller machines. As of mid-2008, required reserves were $71 billion, just 0.6 percent of total bank assets, and vault cash satisfied $43 billion of these requirements. Carpenter and Demiralp (2012) show empirically that the money multiplier does not hold using data from 1990–2007.

[3]For details and complementary analysis of interest on reserves as a monetary policy tool, see Ennis (2014), Ennis and Keister (2008), Keister, Martin, and McAndrews (2008), and Keister and McAndrews (2009). For details and analysis of additional new Federal Reserve monetary policy tools, including overnight

Figure 1. Large Quantity of Reserves in the Banking System

Source: Federal Reserve statistical release H.4.1: Factors Affecting Reserve Balances.

Notes: Frequency: biweekly. Reserve balances with Federal Reserve Banks are the difference between "total factors supplying reserve funds" and "total factors, other than reserve balances, absorbing reserve funds." This item includes balances at the Federal Reserve of all depository institutions that are used to satisfy reserve requirements and balances held in excess of balance requirements. It excludes reserves held in the form of cash in bank vaults, and excludes service-related deposits.

We introduce a new framework in which the role of fiat reserves that pay interest can be studied in a general equilibrium banking economy with a closed system of bank payments and central bank reserves. We include banking, corporate, and retail sectors, which transact in competitive markets for bonds, deposits, loans, and goods. Our benchmark model shows that, without frictions, bank lending quantities and interest rates are invariant to the level of reserves chosen by the central bank. Banks lend up to the point where the marginal return on lending equals the return on holding

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reverse repurchases (reverse "repos") and the term deposit facility (TDF), see Martin et al. (2013), which expands upon the modeling framework in this paper.

reserves, which is equal to the interest rate on reserves set by the central bank. This provides an indifference result for the quantity of reserves. In particular, while the size of banks' balance sheets expands with increases in reserves, all else equal, the lending decision for a bank is determined by the same marginal return condition as with the former method of monetary policy implementation. A loan is made at the margin if its return exceeds the marginal opportunity cost of reserves, whether that is the federal funds rate as in the prior regime or the rate of interest on reserves as in the current regime. We also demonstrate that the quantity of reserves held in the banking system in the absence of binding reserve requirements or significant currency withdrawals is determined in the United States solely by the Federal Reserve. Aggregate bank reserves are independent of and provide no measure of the availability of bank credit or banks' willingness to lend.

We also study costs related to the size of a bank's balance sheet to examine whether the level of reserves affects bank lending under this friction. The concern that banks may face balance sheet costs has been raised by market observers.[4] Banks may have costs that are increasing in the size of their balance sheets because of agency costs or regulatory requirements for capital or leverage ratios. During the recent crisis, banks worked to reduce the size of their balance sheets and were slow to raise equity capital, suggesting an increase in balance sheet costs.[5] Our analysis shows that, with such increasing costs, large quantities of reserves may, surprisingly, have a contractionary effect on bank lending. Large balance sheet costs create a wedge between bank returns paid on deposits and returns received on assets. When returns paid on deposits cannot fall enough in the face of increasing balance sheet costs because of a lower zero bound, increases in reserves can partially crowd out lending and additionally cause disinflation.

The paper proceeds with the model presented in section 2. Section 3 gives results for the benchmark case with no frictions

[4]For example, Wrightson ICAP (2008) expressed the concern that excess reserves could "clog up bank balance sheets" (see also Wrightson ICAP 2009). Ennis and Wolman (2015), however, study the distribution of reserves through 2011 and do not find evidence for such an effect among U.S. domestic banks.

[5]See Martin et al. (2013), which provides a theoretical microfoundation for increasing marginal bank balance sheet costs owing to costly equity requirements that are constrained efficient to overcome banks' moral hazard.

and the cases with balance sheet costs. Section 4 concludes. Formal statements of each proposition and proofs are contained in the appendix.

2. Model

We consider a competitive economy with household, firm, and banking sectors, a central bank, and a government. At date 0, the government issues nominal bonds (B) that can be held by households (B^H), banks (B^B), or the central bank (B^{CB}):

$$B = B^H + B^B + B^{CB}. \tag{1}$$

The central bank has an inelastic demand for bonds, which are purchased by issuing reserves (M) that can only be held by banks:

$$B^{CB} = M. \tag{2}$$

Households are endowed with an amount of wealth w of real goods.[6] The nominal price of goods in terms of the numeraire, reserves, is normalized at date 0 to be 1. Nominal wealth (W) can be held in deposits at banks (D), in government bonds (B^H), and in storage (S),

$$W = D + B^H + S. \tag{3}$$

Banks offer deposits (D) to households and make loans (L) to firms. Firms use the loans to purchase goods from households. These goods serve as input for the firms' investment. At date 1, firms produce output with a marginal real return $r(L)$ on the volume of loans (L). Firms sell their output to households at the date 1 price level of goods. Given our normalization of the price at date 0, this price is equal to the gross level of inflation (Π), i.e., the relative price of goods between dates 0 and 1. We define firms' marginal nominal return on the production and sale of their output as

$$R(L) \equiv \Pi r(L). \tag{4}$$

[6]We use uppercase letters to denote nominal amounts and lowercase letters to denote real amounts throughout the paper.

Firms pay a return (R^L) on the lending from banks, banks pay a return (R^D) on deposits, the government pays a return (R^B) on bonds, and the central bank pays a return (R^M) on reserves (for an interest rate on reserves of $R^M - 1$). The government, central bank, banks, firms, and households are competitive price takers in all markets, which include the markets for bonds, deposits, loans, and goods. For simplicity, we abstract from credit risk, liquidity risk, and risk aversion.[7]

Next, we can write the optimization problems faced by firms, households, and banks. For simplicity, we model each of these sectors as a representative price-taking entity. A firm chooses loans, sells output for revenue ($\int_L R(\hat{L})d\hat{L}$), and repays lending at a return (R^L) in order to maximize profit.[8] The firm's problem is

$$\max_L \int_L R(\hat{L})d\hat{L} - R^L L. \tag{5}$$

A household chooses how many deposits and bonds to hold, which, after paying a lump-sum tax (T), are used to purchase goods. Households keep any remaining wealth in storage, in order to maximize real consumption, given as

[7]During the financial crisis up through September 2008, there was less than \$100 billion in reserves in the banking system. At several points, banks appear to have had a demand for reserves for precautionary reasons that may have affected interest rate spreads for liquidity reasons (see Ashcraft, McAndrews, and Skeie 2011). However, the current paper focuses on the time period starting in late 2009 and beyond, when reserves ranged in the several hundreds of billions of dollars. This level was determined by the Federal Reserve supply for the purchase of assets rather than by bank demand. The ample supply of reserves has easily satisfied any potential liquidity demand for reserves. For analysis of banking fragility in related nominal contracting frameworks, see Allen, Carletti, and Gale (2011), Diamond and Rajan (2006), Martin (2006), and Skeie (2004, 2008); for studies of central bank interest rate policy within these frameworks, see Diamond and Rajan (2009) and Freixas, Martin, and Skeie (2011).

[8]For consistency of terminology, we refer to the (marginal, nominal) return on *lending* as the nominal return R^L that a bank receives from a firm for loans L, where the return R^L on the average of loans L is equal to that on the margin since R^L is a competitive price; the (marginal, nominal) return on *loans* as the marginal nominal return $R(L)$ a firm receives from sales of output goods produced from loans L; and the (marginal) *real* return on *loans* as the marginal real return $r(L)$ in the form of output goods that a firm produces from the investment of input goods purchased with loans L.

$$\frac{1}{\Pi}(R^D D + R^B B^H - T + S). \tag{6}$$

Substituting for deposits ($D = W - B^H - S$) from the household's budget constraint, equation (3), the problem can be written as

$$\max_{B^H,S} \frac{1}{\Pi}[R^D(W - B^H - S) + R^B B^H - T + S]. \tag{7}$$

A bank receives deposits and must choose how many loans to finance (L), as well as how many reserves (M) and how many bonds (B^B) to hold, in order to maximize profits. The bank's problem is

$$\max_{L,M,B^B} R^L L + R^M M + R^B B^B - R^D D - \int_D C(\hat{D}) d\hat{D}, \tag{8}$$

where $C(D)$, the marginal nominal balance sheet cost, is defined as the product of the marginal real cost associated with a balance sheet of size $D, c(D)$, multiplied by the level of inflation, Π,

$$C(D) \equiv \Pi c(D).$$

The bank's balance sheet requires that

$$D = L + M + B^B, \tag{9}$$

so we can write

$$\max_{L,M,B^B} R^L L + R^M M + R^B B^B - R^D(L + M + B^B) - \int_{L+M+B^B} C(\hat{D}) d\hat{D}. \tag{10}$$

The date 0 budget constraints for households, the central bank, and banks given by equations (3), (2), and (9), respectively, together imply that household wealth is divided among loans, storage, and government bonds,

$$W = L + S + B.$$

For a given amount of government bonds, B, maximum lending occurs when there is no storage, which we denote by

$$\bar{L} \equiv W - B.$$

We take as exogenous the government's choice of the quantity of bonds,

$$B = \bar{B},$$

and the central bank's choice of the quantity of reserves and return on reserves,

$$M = \bar{M},$$
$$R^M = \bar{R}^M,$$

respectively. The central bank remits its net revenue ($R^B B^{CB} - R^M M$) to the government, and the government sets the lump-sum tax (T) to repay its debt:

$$T = R^B B - (R^B B^{CB} - R^M M). \tag{11}$$

We make the following assumptions on exogenous parameters and functions:

(A1): $r(L) > 1, r^{'}(L) < 0, r^{''}(L) > 0, r(0) = \infty, \lim_{L\to\infty} r(L) = 1$
(A2): $0 < \bar{M} < \bar{B} < W$
(A3): $c(D) \geq 0, c(0) = 0, c^{'}(D) \geq 0, c^{'}(0) > 0$ if $c(D) > 0, c(\bar{M}) < \infty$.

Assumption (A1) states that the firm's technology is more productive than storage, along with standard Inada conditions. Assumption (A2) considers, for simplicity, monetary and fiscal policy parameters that are strictly within the feasible limit of the economy. Assumption (A3) states that when balance sheet costs are positive, these costs are increasing in the size of the balance sheet.

Letting $\mathbb{R} = (\Pi, R^M, R^L, R^D, R^B)$ and $\mathbb{Q} = (S, M, L, D, B^{CB}, B^H, B^B)$, we define an equilibrium as prices $\mathbb{R} > 0$ and quantities $\mathbb{Q} \geq 0$ such that markets clear at $\mathbb{Q}$ given individual optimizations at $\mathbb{R}$.

The first-order conditions for the firm, household, and bank are

$$L[R^L - R(L)] = 0, \tag{12}$$

$$B^R(R^B - R^D) = 0, \tag{13}$$

$$S(\Pi - R^D) = 0, \tag{14}$$

$$L\left[R^L - R^D - C(D)\right] = 0, \tag{15}$$

$$M\left[R^M - R^D - C(D)\right] = 0, \tag{16}$$

$$B^B\left[R^B - R^D - C(D)\right] = 0. \tag{17}$$

We focus on interior solutions. Since households can invest in both government bonds and deposits, they must have the same return for any interior solution, so we can write $R^D = R^B$. Since M and L are strictly positive, firms borrow loans to the point where their first-order condition binds, $R(L) = R^L$. Lending financed by banks have a return equal to the return paid on reserves, $R^L = R^M$.

3. Results

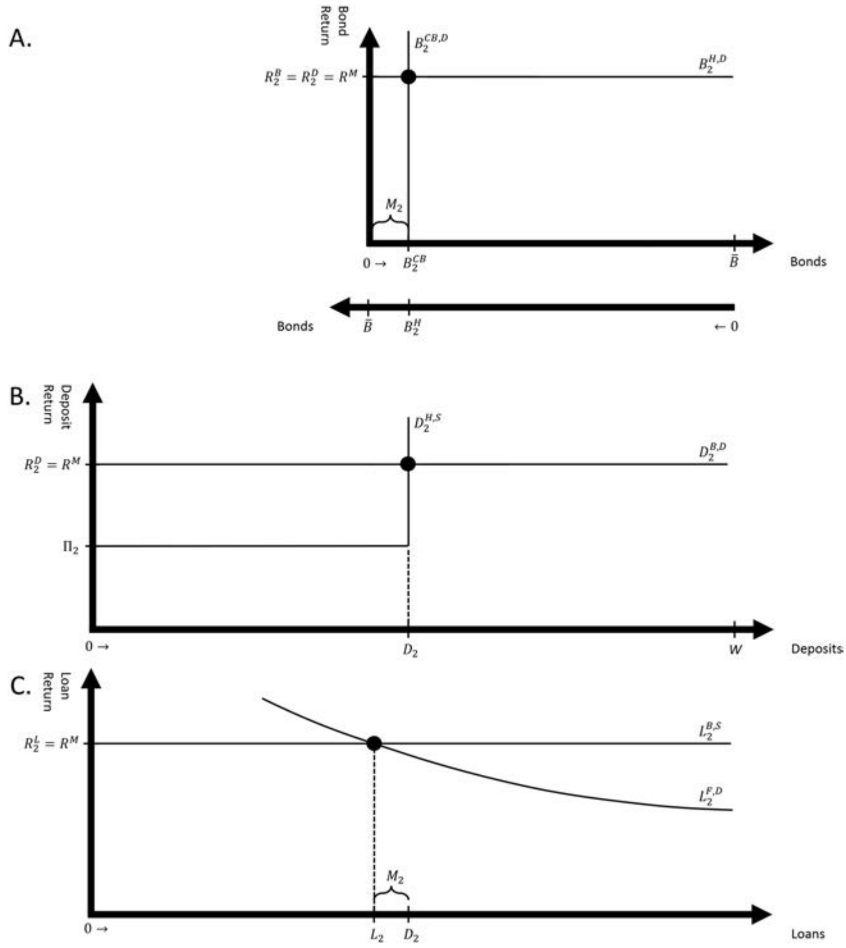
3.1 Benchmark Case

We first consider the benchmark case with no balance sheet costs, $c(D) = 0$. In equilibrium, a firm's return on a marginal loan, $r(L)$, and hence the quantity of loans financed, L, is independent of the quantity of reserves, M. This provides our first basic result.

PROPOSITION 1. *In the benchmark case with no balance sheet costs, there exists an equilibrium that is unique up to the allocation of bonds between households and banks. The quantity (L) of and return (R^L) on bank lending are independent of the quantity of reserves (M) issued by the central bank. Market returns (R^M, R^L, R^D, R^B) are equal to the return on reserves set by the central bank ($\bar{R}^M$) and are greater than inflation* (Π).

Figures 2 and 3 illustrate the effects of minimal and moderate levels of reserves, respectively, on the equilibrium in the benchmark case with no balance sheet costs. For simplicity, we focus on the case where banks do not hold any bonds, $B^B = 0$. Panel A in each figure shows the available bonds, $\bar{B}$, in the government bond market that must be split between the central bank and households. The central bank's demand for bonds, represented in figure 2 by $B_2^{CB,D}$, is perfectly inelastic and corresponds to the quantity purchased with the level of reserves M_2, where subscripts in the figures correspond to the figure numbers 2–5. Households purchase all the bonds B_2^H not bought by the central bank.

Figure 2. Benchmark Model with Minimal Reserves and No Balance Sheet Costs



Notes: Superscripts "CB," "H," "B," and "F" denote "central bank," "household," "bank," and "firm," respectively; superscripts "S" and "D" denote "supply" and "demand," respectively. Subscript numbers correspond to the figure in which a particular supply or demand curve, or an equilibrium quantity, rate, or locus of points, is first determined.

A. Bond Market. Central bank bond holdings B^{CB} increase rightward on the x-axis of the bond market graph. Household bond holdings B^H increase leftward on the x-axis below the graph. The central bank has a perfectly price-inelastic demand for bonds $B_2^{CB,D}$, issuing M_2 reserves to buy B_2^{CB} out of total government bond supply $\overline{B}$. The excess bond supply available to households, $\overline{B} - B_2^{CB}$, is perfectly price inelastic. The locus of points corresponding to a price-taking household's equilibrium demand for bonds, $B_2^{H,D}$, is perfectly elastic at the level of the return on bonds, R^B, that is equal to the equilibrium return on deposits, R_2^D. This reflects that a household is indifferent between bonds and deposits. Households' aggregate bond purchase is labeled B_2^H.

(continued)

(Notes for figure 2, continued):

B. Deposit Market. The locus of households' aggregate supply of deposits consistent with market clearing conditions for an equilibrium, D_2^S, is perfectly price inelastic at the quantity of deposits D_2, which is equal to household wealth W (indicated on the x-axis) not held in bonds: $D_2 = W - B_2^H$. A bank's demand for deposits $D_2^{B,D}$ is perfectly elastic at $R_2^D = R^M$, reflecting an indifference to holding additional reserves funded by deposits.

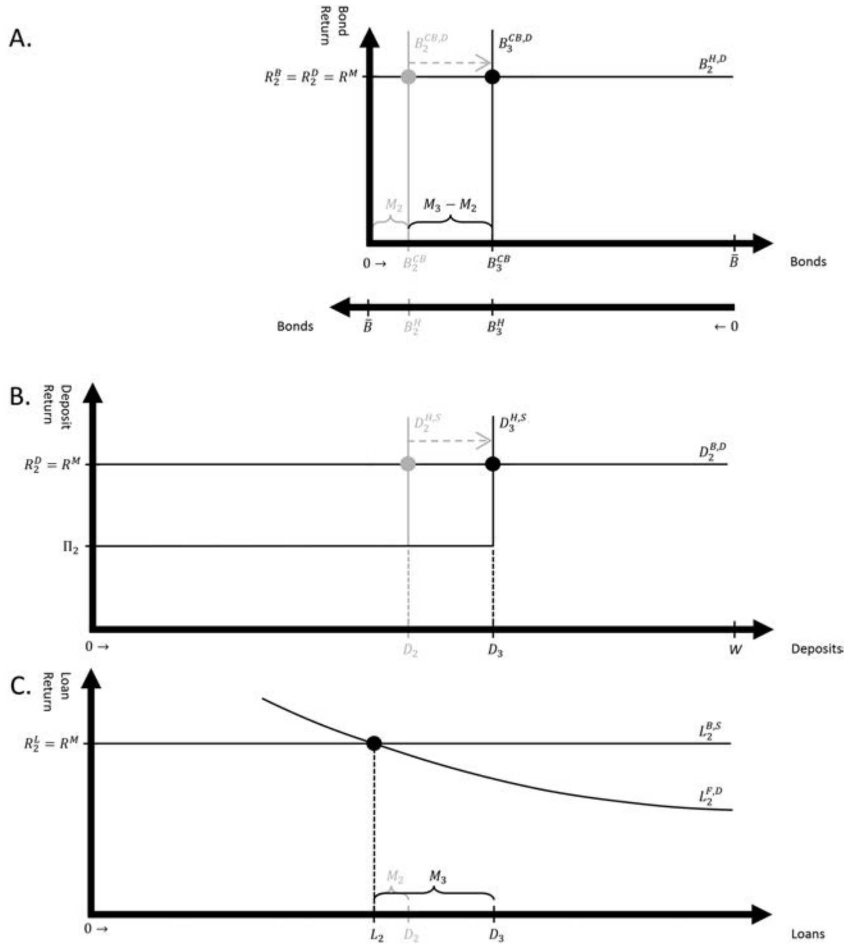
C. Loan Market. Firms have a downward-sloping demand curve for loans $L_2^{F,D}$, reflecting a price-taking firm's decreasing marginal real return on investment. A bank's supply of loans $L_2^{B,S}$ is perfectly elastic at the level of the return on lending that is equal to the return on reserves: $R_2^L = R^M$. This reflects that a price-taking bank is indifferent between holding loans and reserves. The equilibrium quantity of loans, equal to a bank's deposits minus reserves, $L_2 = D_2 - M_2$, determines the level of gross inflation, $\Pi_2 = \frac{R^M}{r(L_2)}$, which is shown in panels A and B.

Panel B represents the deposit market. Since there is no storage held, deposits, D_2, are determined by the difference between the wealth of households and their bond holdings. The vertical line $D_2^{H,S}$ represents the locus of the aggregate supply of deposits by households consistent with market clearing conditions for an equilibrium. Note that from equations (13) and (16), the supply of deposits by an individual household is perfectly elastic at the interest rate paid on reserves by the central bank. That said, the quantity of deposits supplied in equilibrium will be the same for any level of $\bar{R}^M$. This is because households' wealth is divided between deposits and bond holdings. And, as noted above, households' aggregate bond holdings are determined by the difference between the total stock of bonds and bonds purchased by the central bank. This also implies that households' aggregate deposits increase with the level of reserves issued by the central bank.

A bank has a perfectly elastic demand curve for deposits because any additional deposit gives the bank an additional reserve asset, which pays R^M. Panel C shows that in the loan market, firms' loan demand, $L_2^{F,D}$, determined by (12), is decreasing in the return on lending, R^L, and reflects the fact that $r(L)$ is decreasing in L. A bank's supply of lending, $L_2^{B,S}$, is perfectly elastic at the return on reserves, $\bar{R}^M$, which is the bank's opportunity cost for holding loans.

The quantity of banks' loans is independent of the supply of reserves and only depends on the return paid on reserves, highlighted

Figure 3. Moderate Level of Reserves and No Balance Sheet Costs



Notes:

A. Bond Market. An increase in the central bank inelastic demand for bonds to $B_3^{CB,D}$ increases reserves to M_3 and decreases households' bond holdings by the increased amount of reserves to B_3^H.

B. Deposit Market. Households' aggregate equilibrium supply of deposits $D^{H,S}$ remains inelastic and increases by the amount of households' decrease in bond holdings.

C. Loan Market. With no balance sheet costs, deposits increase exactly by the amount of the increase in reserves, showing that the return on lending R^L, the quantity of loans L, and hence inflation Π, are independent of the quantity of reserves M.

by the result that in equilibrium $R(L) = R^L = R^M$. This is an especially robust relationship that holds throughout the paper, even when balance sheet cost frictions are added in the next section. These equalities allow for substituting R^M for $R(L)$ in equation (15), which rearranged shows that inflation is determined throughout the paper as

$$\Pi = \frac{R^M}{r(L)}. \tag{18}$$

This expression for inflation shows why there is no household storage when there are no balance sheet costs. As stated by the households' first-order condition (14), there is no storage in equilibrium when the nominal return on deposits R^D is greater than inflation Π, or equivalently when the real return on deposits $\frac{R^D}{\Pi}$ is greater than one, the return on storage. In the case of no balance sheet costs, the real return on deposits, $\frac{R^D}{\Pi}$, is equivalent to $\frac{R^M}{\Pi}$, which by equation (18) equals the marginal real return on firm production, $r(L)$, greater than one. Equation (18) also highlights that in this model, inflation is always below the return on reserves R^M chosen by the central bank, which can be see in figures 2 and 3.

In figure 2, with minimal reserves, equilibrium loans are equal to nearly the full quantity of deposits. In figure 3, with a moderate level of reserves, loans comprise a smaller share of banks' assets. Instead, the size of banks' balance sheets increases to fund both their loans to firms and the reserves issued by the central bank.

Figure 3 also demonstrates that the quantity of reserves held in the banking system is determined solely by the central bank's quantity of bond purchases. The level of bank reserves is independent of, and unaffected by, banks' supply of loans to firms. This means that whether bank reserves are high or low gives no indication of the amount of bank lending that is occurring. Equivalently, the amount of bank lending has no implication for the quantity of bank reserves held by banks.

3.2 Balance Sheet Costs

Next, we consider the case of positive bank balance sheet costs. This is an important and natural friction to consider, since market participants have raised concern that banks' balance sheets may be too large (Wrightson ICAP 2008, 2009). Bank balance sheet costs may incorporate the costs of capital requirements and the shadow cost of potentially binding capital ratios.[9]

If $c(D) > 0$, then banks will reduce the size of their balance sheets by not holding bonds, $B^B = 0$. Households are at a corner solution of holding the government bonds not held by the central bank. A positive balance sheet cost for banks $c(D) > 0$ does not necessarily affect the amount of bank lending, and $R^L = R^M$ still holds for moderate balance sheet costs and reserve quantities. Instead, the return on deposits paid by banks is reduced: $R^D = R^M - C(D) < R^M = R(L)$. Banks' return on marginal lending, R^L, is not equal to banks' marginal funding costs, R^D, but rather is equal to the return on reserves, R^M, the alternative assets in which banks can invest.

PROPOSITION 2. *For moderate balance sheet costs, $c(D)$, and reserve levels ($\bar{M}$), the return (R^L) on lending by banks equals the return on reserves ($\bar{R}^M$). These returns are greater than the returns on deposits and bonds, which are equal ($R^D = R^B$), and which in turn remain above inflation (Π). The amount of bank-sector lending (L) is independent of the amount of reserves ($\bar{M}$).*

Households' supply of deposits and a bank's demand for deposits are endogenous, and hence the size of banks' balance sheets is endogenous. The government bond return and the deposit return are both determined in equilibrium according to households' first-order conditions. Because households always hold bonds and deposits in equilibrium, their two returns must be equal to make the household indifferent between holding the two assets. When there are positive balance sheet costs, the deposit return falls below the bank's return on its assets (the return on reserves, which equals the lending return)

[9] We do not explicitly model bank capital, which is implicitly incorporated in banks' balance sheet liabilities (D). As a result, bank capital, which may need to be raised during times of distress to support continued or increased bank balance sheet size because of bank capital and leverage ratio requirements, may be an important part of a bank's balance sheet costs, $c(D)$. Carlson, Shan, and Warusawitharana (2011) argue that higher capital ratios may support greater loan growth, particularly in times of distress, an argument for which they find evidence during the recent financial crisis. The reluctance of many banks to raise capital during the crisis indicates that capital may be particularly costly to raise in times of distress.

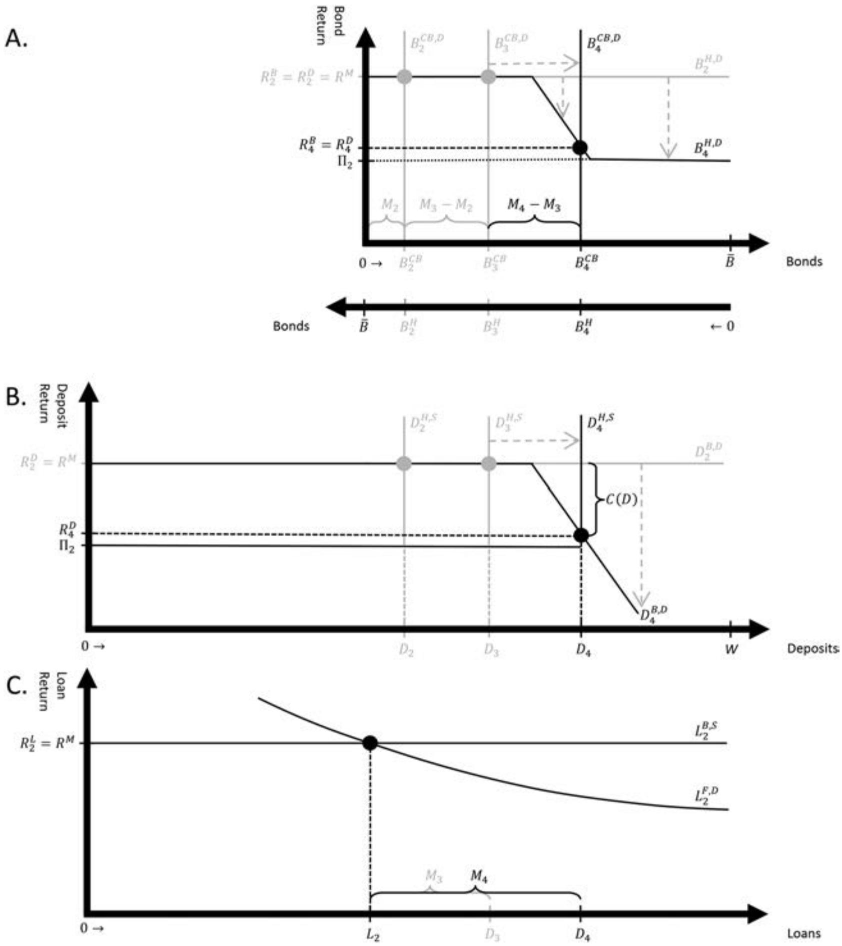
in order for the bank to be willing to hold a marginal deposit and a marginal asset. Thus, the government bond return falls below the banks' other asset returns, and banks prefer then to hold reserves and loans but zero bonds.

The invariance result of moderate balance sheet costs and reserves on bank lending is illustrated in figure 4. The equilibrium returns on deposits and government bonds are equal to and below the return on reserves: $R^D = R^B < \bar{R}^M$. The decrease in the return on deposits absorbs the balance sheet cost. Banks do not incur the balance sheet cost in their borrowing rates and do not pass the cost on through higher lending rates. Households receive the surplus from the banking sector at the margin. Households are willing to absorb the balance sheet costs as long as the marginal real return on deposits, $\frac{R^D}{\Pi}$, is greater than the return on storage, equal to one. In contrast, since banks operate competitively with a zero marginal-profit condition, they are not willing to absorb losses at the margin.

In panel A, the locus of points corresponding to households' equilibrium aggregate demand for bonds, $B_4^{H,D}$, becomes downward sloping in the region corresponding to positive balance sheet costs. The downward slope follows that of the bank's demand curve for deposits. The decrease in deposit returns decreases households' reservation rate for bonds, since the bond return must be equal to deposit return in equilibrium. However, as long as the return on deposits remains above inflation, the real return on deposits is greater than the return on storage. The locus of points corresponding to households' aggregate supply of deposits, $D_4^{H,S}$, remains vertical in panel B, equal to the share of wealth that is not held in bonds. The quantity of bank lending is unchanged from the benchmark case of zero balance sheet costs.

Finally, for large enough reserves and balance sheet costs, the net real deposit rate hits a zero real lower bound that leads to a reduction in real bank lending and disinflation. This occurs when the nominal deposit return, as given by $R^D = R(L) - C(D)$, falls to the nominal lower bound given by households' option to store goods at the nominal level of inflation instead of holding deposits. At this point, according to households' first-order condition (14), the real return on deposits is equal to that of storage, $\frac{R^D}{\Pi} = 1$. The nominal

Figure 4. Moderate Level of Reserves and Moderate Balance Sheet Costs



Notes:

A. Bond Market. For implied deposit quantities in the region where banks have positive balance sheet costs, a household's bond demand $B^{H,D}$ slopes downward from left to right. $B_4^{H,D}$ corresponds to the bank's downward-sloping demand for deposits $D_4^{B,D}$ in panel B. This again reflects a household's indifference between holding bonds or deposits, which in equilibrium must have equal returns that are determined in the deposit market according to the bank's deposit demand.

B. Deposit Market. The locus of points corresponding to households' aggregate inelastic supply of deposits $D_4^{H,S}$ increases by the decreased amount of household bonds. In the region of positive balance sheet costs, a bank's marginal balance sheet cost $C(D)$ increases with balance sheet size D and lowers the bank's demand for deposits $D^{B,D}$ below R^M by $C(D)$, pushing the balance sheet cost onto depositors. As a result, when reserves increase to M_4, households' bonds decrease to B_4^H, and deposits increase to D_4, which decreases the return on deposits and bonds to $R_4^D = R_4^B = R^M - C(D_4)$.

(continued)

(Notes for figure 4, continued):

C. Loan Market. With a moderate level of reserves and bank balance sheet costs, loans, lending returns, and inflation again remain unchanged. Deposits can increase with reserves because deposit returns are able to absorb the balance sheet costs.

return on deposits cannot fall below the level of inflation, because that would imply a real return on deposits below one: $\frac{R^D}{\Pi} < 1$. Households would prefer only to store goods.

Together, these constraints imply that bank lending will be reduced to a level such that the net marginal real rate of return on loans equals the marginal real bank balance sheet cost:

$$r(L) - 1 = c(D). \tag{19}$$

Lending in the economy can increase only to the point that the marginal real productivity of loans over that of the opportunity cost of storage equals the marginal real balance sheet cost, which is the real banking cost of intermediating loans. When reserves, M, are so large that (19) holds, reserves partially crowd out bank lending. This crowding-out effect is independent of the central bank's interest rate policy $(R^M - 1)$, as seen by the condition for no crowding out to occur, which is that the real return on deposits is greater than one: $\frac{R^D}{\Pi} = r(L) - c(D) > 1$.

PROPOSITION 3. *For a large enough supply of reserves (M) and balance sheet costs, $c(D)$, the return on deposits (R^D) and bonds (R^B) decreases to equal the level of inflation (Π). Bank lending (L) and inflation (Π) are decreasing in the quantity of reserves (M).*

The volume of loans continues to be determined according to $R(L) = R^M$. The nominal return on loans remains constant, since by $R(L) = \Pi r(L)$, the lower level of inflation offsets the higher marginal real return on the lower level of loans. Regardless of how high balance sheet costs are, a bank is always indifferent between holding marginally more loans or reserves, and so the returns are equal. The bank chooses its optimal amount of reserves according to a demand curve for reserves. The central bank chooses a quantity of reserves to supply, which is a point on the bank's demand curve and hence satisfies the bank's optimal demand. We have endogenized the lower bound on deposit returns by including the household's option to store goods. This implies that in equilibrium, the net real rate of return on deposits, $\frac{R^D}{\Pi} - 1$, cannot fall below zero (or equivalently that the real return on deposits of $\frac{R^D}{\Pi}$ cannot fall below one). Without the availability of storage, the quantity of lending would not be affected by the quantity of reserves or the size of balance sheet costs.

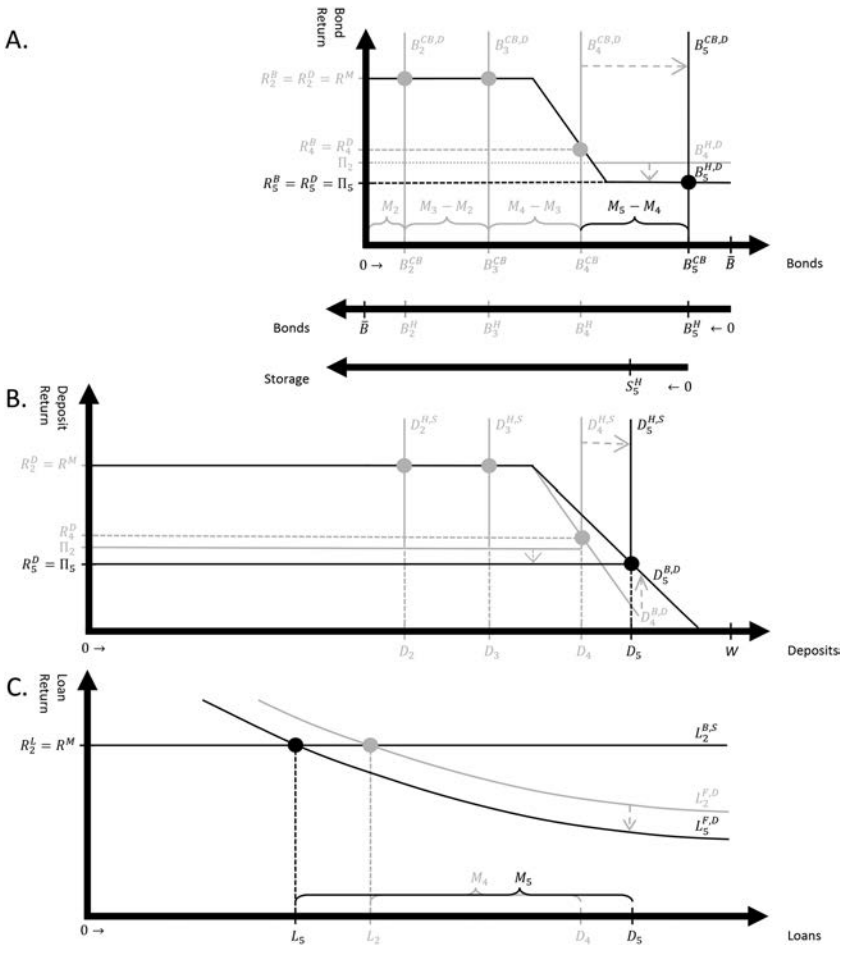
Bank loans are equal to deposits held in excess of reserves, $L = D - M$. As shown in figure 5, when bank balance sheet costs and reserves are large enough that R^D is at the lower bound, at the margin a unit of reserves increases balance sheet costs by $c(D)$. Constraint (19) requires a corresponding increase in the real return on loans and hence a reduction in lending. This decrease is held in storage by households. In sum, an additional unit of reserves purchases a unit of bonds for the central bank from the households. Households hold a fraction of the unit of wealth as deposits and the remaining fraction as storage. Since banks can fund only a fraction of the additional unit of reserves with the additional fraction of deposits, banks must decrease lending by the remaining fraction.

The return on government bonds, R^B, also falls along with the return on deposits, R^D, to the lower nominal bound of the inflation level, Π. The return on deposits and bonds is below the return on reserves by the balance sheet cost wedge of $1 + c(D)$: $R^D = \frac{R^M}{1+c(D)} < R^M$.

In this case of large reserves crowding out bank lending, large reserves have the further effect of creating disinflation. Decreased lending raises the marginal real return on loans, which requires inflation to be lower following the determination $\Pi = \frac{R^M}{r(L)}$ than what it would be without large balance sheet costs and large reserves. The decrease in inflation from fewer loans is partially but not fully offset by the increase in marginal real balance sheet costs from a larger balance sheet in determining the lower equilibrium return on deposits: $R^D = R^M - \Pi c(D)$. This shows that inflation can also be expressed as $\Pi = \frac{R^M}{1+c(D)}$, where $\frac{\partial \Pi}{\partial M} < 0$.

Disinflation also partially offsets the increase in real marginal balance sheet costs that accompany increased deposits, as shown by $R^D = R^M - \Pi c(D)$, since lower inflation partially mutes the increase in nominal marginal balance sheet costs. Without this effect, once at

Figure 5. Large Level of Reserves and Large Balance Sheet Costs



Notes:

A. Bond Market. Once a household's downward-sloping bond demand $B^{H,D}$ falls to a low enough household-bond quantity B^H such that it receives an equilibrium bond return that falls to the level of inflation, $R^B = \Pi$, the household's bond demand becomes perfectly price elastic at the inflation level for any smaller quantities of household bonds. This price elasticity, as also illustrated in figure 4, reflects that households prefer to hold storage S for a real return of one rather than bonds for a real return of less than one, which would occur for nominal returns of $R^B < \Pi$. When the central bank demand for bonds $B^{CB,D}$ increases enough to intersect with the elastic segment of household bond demand, households begin to hold positive amounts of storage. Storage is measured on the second x-axis below the bond market graph from right to left. The zero value of the storage x-axis lines up with the quantity of bonds held by households, B_2^H, in order to indicate that the amount of storage held is equal to household wealth, shown by W on the deposit x-axis, that is not held in bonds or deposits.

(*continued*)

(Notes for figure 5, continued):

B. Deposit Market. Households' supply of deposits $D^{H,S}$ is perfectly elastic at $R^D = \Pi$ for deposit quantities below the amount of household wealth not held in bonds or storage in equilibrium, $W - B^H - S$, as also illustrated in figures 2–4. This elasticity reflects, similarly to that of household bond demand, the preference to hold storage rather than deposits that pay a real return less than one. Hence, the increase in reserves push nominal deposit and bond returns down to the inflation level, $R_5^D = R_5^B = \Pi_5$, with their real returns hitting the real zero rate lower bound. Since households replace the decrease in their bond holdings in part with storage, the increase in household deposits is less than the increase in reserves by the amount of storage: $\Delta D = \Delta M - \Delta S$.

C. Loan Market. With reserves increasing by more than deposits, loans must decrease with the increase in reserves by an amount equal to the increase in storage: $\Delta L = \Delta D - \Delta M = -\Delta S$. A lower quantity of loans raises their marginal real return, which requires inflation to decrease to $\Pi_5 = \frac{R^M}{r(L_5)}$, as shown in panels A and B. Hence, for large enough balance sheet costs, increases in reserves crowd out bank lending and decrease inflation. The decrease in inflation shifts firms' nominal loan demand leftward to $L_5^{F,D}$, such that the nominal return on marginal loans $\Pi_5 r(L_5)$ equates to the unchanged return on lending $R(L_2)$ and return on reserves R^M. At the zero lower bound, decreasing inflation allows deposits to expand partially with increasing reserves, so loans do not fall by the entire amount of the increase in reserves. Deposits partially increase with reserves because the perfectly elastic segments of household bond demand in panel A and deposit supply in panel B shift with the decrease in inflation down to $B_5^{H,D}$ and $D_5^{H,S}$, respectively. In addition, while the return on a bank's demand for any additional deposits would otherwise fall below the level of inflation from increasing marginal real balance sheet costs, the decrease in inflation partially offsets this movement downward along $D_4^{B,D}$. This disinflation rotates the downward-sloping segment of the bank's deposit demand upward, pivoting around the kink in $D^{H,D}$, to D_5^D, which allows for slightly higher deposit returns, $R^D = R^M - \Pi c(D)$, and a further partial increase in deposits with reserves. (For simplicity, the corresponding upward pivot of $B^{H,D}$ with the fall in inflation in panel A is not shown.)

the zero lower bound, increases in reserves would lead households' decrease in bonds to a one-for-one increase in storage, no increase in deposits, and a one-for-one decrease in loans, for an entire crowding out of loans from additional reserves.

In this case of disinflation, the inflation rate may still be positive, in which case the deposit rate remains positive: $R^D - 1 = \Pi - 1 > 0$. However, actual deflation may also occur, in which the inflation rate $\Pi - 1$ falls below zero. Nominal deposit and bond rates, $R^D - 1$ and $R^B - 1$, respectively, would be negative. The real deposit and bond rates, $\frac{R^D}{\Pi} - 1$ and $\frac{R^D}{\Pi} - 1$, respectively, would remain equal to zero.

3.3 Discussion

We can discuss several potential extensions that lie outside the formal model, including the effect of macroeconomic shocks on bank lending, bank heterogeneity, and historical regimes for reserves.

To start, we examine how shifts in parameters can affect bank lending. First, we consider an increase in loan demand driven by a productivity shock. We compare the effect of an increase in the marginal real return on firms' investment up to $\tilde{r}(\cdot) > r(\cdot)$ for the cases of minimal versus large sizes of reserves and balance sheet costs. With minimal reserves, an increase in productivity leads to a decrease in inflation since $R(\cdot) = \Pi r(\cdot) = R^M$. The marginal nominal return of bank lending is unchanged and there is no change in lending.

With large reserves and balance sheet costs, an increase in real productivity to $\tilde{r}(\cdot) > r(\cdot)$, for a given level of loans L, increases the left-hand side of equation (19). There is an increase in equilibrium loans to $\tilde{L}$, which moderates the equilibrium increase in productivity to $\tilde{r}(\tilde{L})$. There is an increase in deposits, $\tilde{D} - D = \tilde{L} - L$, and in bank balance sheet costs $c(\tilde{D})$, to the point that equation (19) holds: $\tilde{r}(\tilde{L}) - 1 = c(\tilde{D})$. The increase in loans is supported by a decrease in household storage of $S - \tilde{S} = \tilde{L} - L$. This shows that an increase in loan demand driven by a positive real productivity shock leads to an increase in bank lending. However, the increase in the equilibrium marginal real return on loans to $\tilde{r}(\tilde{L})$ is complemented by a decrease in inflation to $\tilde{\Pi}$, because firms' marginal nominal return on loans, $\Pi\tilde{r}(\tilde{L})$, is tied to the return on lending, R^L, and return on reserves, R^M: $\Pi\tilde{r}(\tilde{L}) = R^L = R^M$. Again, we find overall that $\tilde{R}(\tilde{L}) = R^L$; the marginal nominal return on loans is unchanged.

Next, we consider an increase in loan demand that is driven by an increase in households' demand. We examine the effect of a increase in household wealth up to $\tilde{W} > W$, when there is a low or moderate size of reserves and balance sheet costs. The increase in wealth leads to an increase in households' supply of deposits and an increase in inflation, which shifts out firms' demand for loans, lowering firms' real return on investment. The increase in equilibrium deposits, loans, and inflation is given by $(\tilde{D} - D) = (\tilde{L} - L) = (\tilde{W} - W)$ and $(\tilde{\Pi} - \Pi) = \left(\frac{R^L}{r(\tilde{L})} - \frac{R^L}{r(L)}\right)$.

By using comparative statics, the model in essence allows for analyzing an instantaneous adjustment of deposits and loans regardless of the level of bank reserves. However, in practice, a lower velocity of money is required for a banking system with a higher level of reserves than for one with a lower level of reserves. The banking sector lends out of the quantity of reserves it holds, M, to firms that buy goods from households, who deposit the reserves in the banking system. The reserves have to turn over $\frac{\tilde{L}-L}{M}$ times for an increase in deposits up to $\tilde{D}$ and in loans up to $\tilde{L}$. Outside of the model, if there is heterogeneity among banks, it may take some time or cost for the adjustment process of banks that have suddenly increased lending opportunities to attract deposits or interbank loans. A higher quantity of reserves requires a lower velocity of money and may lead to a slightly faster increase in lending in response to a sudden increase in loan demand. Hence, the level of reserves could affect the speed at which equilibrium levels of lending would adjust to shocks in the economy. For either driver of increased loan demand above, we see that faster adjustment cost speeds that may result from larger reserve levels produce more efficient outcomes.

These adjustment effects may also provide insight into the consideration of the extreme heterogeneity of the banking sector in the United States. We model a representative bank that makes a representative type of loan to firms. In reality, banks in the United States vary tremendously in many features, including bank size, sources of deposits, and focus of lending (for instance, see Janicki and Prescott 2006). For example, banks provide commercial and industrial loans, real estate loans, and consumer loans. While aggregate reserves in the banking system are fixed by the Federal Reserve, the distribution of reserves among banks is not fixed and may depend on bank size, deposit sources, and lending focus. Outside of the model, we can consider that such variation among banks may lead to different speeds of adjustment to changes in bank borrowing and lending. For example, banks that have greater access to wholesale deposits can increase or decrease borrowing and hence lending faster than banks that rely more on retail deposits. However, we do not expect that variation among bank types or the speed of adjustments of bank borrowing and lending would lead to a significant change in our equilibrium results.

We can also use the model to compare the current regime of interest on reserves with past regimes. Historically, central banks used a reserve requirement ratio in order to create a demand for reserves on which they did not pay interest and to control the amount of bank loans through the money multiplier. For a reserve requirement ratio of ρ, the money multiplier is $\frac{1}{\rho}$. With a supply of reserves (M) as chosen by the central bank, and under a binding money multiplier constraint, the banking sector could hold a maximum amount of deposits equal to $D = \frac{M}{\rho}$ and provide a maximum amount of loans equal to $L = \left(\frac{1-\rho}{\rho}\right) M$. Over time, most central banks have either eliminated reserve requirements entirely or have allowed banks to largely avoid them, such as through sweep accounts in the United States. Our model of bank lending, with interest on reserves and no meaningful reserve requirement, shows that the money multiplier is no longer relevant. Banks take deposits and lend to the point that the marginal return on loans $R(L)$ equals the return R^M paid by the central bank on reserves, the banks' alternative asset.

In past regimes that did not pay interest on reserves, reserve requirements were considered to impose a "tax" on banks. This tax is the return that banks had to forgo by holding required reserves that paid no return, equal to $\rho DR(L)$. In comparison, under a policy of interest on reserves, banks no longer face the tax on required reserves. However, with a large quantity of reserves in the banking system, banks face the potential additional balance sheet costs from large levels of reserves, equal to $\int_D C(\hat{D})d\hat{D} - \int_L C(\hat{L})d\hat{L}$. Relative to the implicit tax on the modest level of required reserves that did not receive interest in past regimes, the balance sheet costs from reserves that do receive interest in the current regime would be smaller in times of low levels of reserves but would likely be much greater in times of high levels of reserves.

4. Conclusion

Perhaps because of its novelty, the large quantity of reserves in the banking system has generated a great amount of concern and debate. However, there is little analysis of how reserves affect bank lending when interest is paid on reserves. This paper presents a model of the current U.S. banking system that includes interest on reserves and no binding reserve requirements. The exercise is important because of expressed concerns that large reserves could lead to excessive lending by banks, despite little formal analysis of the issue.

We develop a complete yet parsimonious framework by fully specifying a general equilibrium economy with several competitive sectors and a closed system of reserves and payments within the banking system. We study households' supply of deposits and demand for bonds and consumption goods; firms' demand for loans and supply of consumption goods; and banks' supply of loans and demand for deposits, bonds, and reserves. While we consider a representative competitive price-taking bank, it would be interesting in future research to consider banks that are not fully price taking, such as banks that may have some monopoly power on deposits and loans.

We show that without frictions, the amount of lending is independent of the amount of reserves in the banking system. We also demonstrate that the quantity of reserves is determined by the Federal Reserve and does not provide any measure of the willingness of banks to lend. We have kept our model simple and elementary in order to illustrate that the key determinant of bank lending is not fundamentally affected by the quantity of reserves. This point has been obscured by the traditional textbook model of the money multiplier, which, while simple, is not an elementary model. Rather, that model assumes that a particular constraint—namely, the money multiplier—is always binding.

Our conclusion is likely to hold in more sophisticated models. While we cannot exclude the possibility that a more complicated model would overturn this result, economists concerned that large reserves will generate excessive lending should articulate precisely which frictions in a banking model will necessarily lead to this result. In contrast to such concerns, we study a friction under which the quantity of reserves could crowd out bank lending and lead to a decrease in inflation. Banks may have increasing costs in the size of their balance sheets because of agency costs or regulatory requirements on capital or leverage. Under such a friction, the effect of large reserves is contractionary rather than expansionary.

Appendix. Proofs

Proof of Proposition 1

We will show that if $c(D) = 0$, then there exists an equilibrium $(\mathbb{Q}, \mathbb{R})$ where $R^M = R^L = R^D = R^B = \bar{R}^M > \Pi$, which is unique up to the allocation of bonds between households and banks.

In any equilibrium, equations (1), (3), and (2) must be satisfied. The central bank's choice of reserves supply and the return on these reserves requires that $R^M = \bar{R}^M$ and $M = \bar{M}$. We first show that there does exist an equilibrium with $R^M = R^L = R^D = R^B = \bar{R}^M > \Pi$. Consider $R^M = R^L = R^D = R^B = \bar{R}^M$. We have banks indifferent between holding bonds, reserves, and loans, and households indifferent between holding deposits and bonds. Consider Π such that $r(\bar{L}) = \frac{R^L}{\Pi}$. By (A1) such a Π exists and $\Pi < R^L$. Now consider $D = \bar{L} + \bar{M}$, $B^B = 0$, $B^{CB} = \bar{M}$, $B^H = \bar{B} - \bar{M}$, $L = \bar{L}$, and $S = 0$. Clearly these quantities satisfy individual optimizations at the given prices, are non-negative given (A2), and clear the market. Thus, this is an equilibrium at $R^M = R^L = R^D = R^B = \bar{R}^M > \Pi$.

To see how Π is determined, note that in equilibrium, real investment by firms plus real storage by households s must be equal to the difference between real wealth w and the government's choice of real bonds b to issue. This difference is a fixed amount, given the quantity of reserves M issued by the central bank, the real balance sheet cost function $c(D)$, and the real marginal return on firm investment $r(L)$. Π must adjust so that the solution to the firms' problem, given by (5), is exactly that amount of real investment by firms.

To show uniqueness we argue that $R^M = R^L = R^D = R^B = \bar{R}^M > \Pi$ must hold in any equilibrium, and that $L = \bar{L}$ and $S = 0$ in any equilibrium. This will imply that all equilibria are unique up to the allocation of bonds between households and firms since in equilibrium $M = \bar{M}$. Since $r(L) > 1$, we must have $R^L > \Pi$ in any equilibrium; otherwise, firms' first-order conditions could never be satisfied. (A1) also requires that $L > 0$, which in turn implies that $R^M = R^L \geq R^B$ since $\bar{M} > 0$. Also, we must have $R^M = R^L = R^D$, for inequality would imply that banks would demand either zero or infinite quantities of deposits. Market clearing in the bond market then requires that $R^M = R^L = R^D = R^B$. Since we always must have $R^M = \bar{R}^M$, we have that $R^M = R^L = R^D = R^B = \bar{R}^M > \Pi$ in any equilibrium. Now $R^D = R^B > \Pi$ directly implies that $S = 0$, which in turn implies that $L = \bar{L}$ since households must expend their entire wealth. In sum, we have that any potential equilibrium must have $R^M = R^L = R^D = R^B = \bar{R}^M > \Pi$, $L = \bar{L}$, and $S = 0$. Thus, the equilibrium is unique up to the allocation of bonds between households and firms.

Proof of Proposition 2

We will show that if $c(D) > 0$ and $c(\bar{M} + \bar{L}) \leq r(\bar{L}) - 1$, then there exists a unique equilibrium $(\mathbb{Q}, \mathbb{R})$ where $L = \bar{L}$ and $R^M = R^L = \bar{R}^M > R^D = R^B \geq \Pi$.

Because of (A3), (12), and (15) we must have $R^L > R^D$. (A1) requires $L > 0$ and (A2) requires $M > 0$ in equilibrium, thus we must have $R^M = \bar{R}^M = R^L$. Once again, market clearing in the bond market then requires that $R^D = R^B \geq \Pi$. In sum, we have that $R^M = \bar{R}^M = R^L > R^D = R^B \geq \Pi$. Now, we show that there is an equilibrium with $L = \bar{L}$. We first find an R^D and Π such that $R^D = R^L - \Pi c(\bar{M} + \bar{L})$ and $\Pi = \frac{R^L}{r(\bar{L})}$; i.e., consumption of $\bar{L}$ must be optimal for both banks and firms. As (A3) guarantees that $\bar{L} > 0$, we have that $\Pi > 0$. Thus, $R^D = R^L - \left(\frac{R^L}{r(\bar{L})}\right)(c(\bar{M} + \bar{L})) < R^L$. Furthermore, $c(\bar{M} + \bar{L}) \leq r(\bar{L}) - 1$ implies that $R^D \geq \frac{R^L}{r(\bar{L})} = \Pi$. Finally, setting $R^D = R^B$, we have an equilibrium where $\mathbb{Q} = (\bar{M}, \bar{L}, \bar{L} + \bar{M}, \bar{M}, B - \bar{M}, 0)$. To see that this is unique, consider a potential equilibrium loan quantity $L^{'} \neq \bar{L}$. Clearly, $L^{'} < \bar{L}$, but this implies that $S > 0$, since $R^M = R^L = \bar{R}^M > R^B$ implies that banks will not hold bonds and households need to expend all of their wealth. $S > 0$ implies that $R^D = R^B = \Pi$. However, if $c(\bar{M} + \bar{L}) \leq r(\bar{L}) - 1$, then $c(\bar{M} + L^{'}) < r(L^{'}) - 1$, which implies that $R^D > \Pi$ for $L^{'}$ to be optimal loan consumption for both banks and firms. Thus, $L^{'}$ cannot be an equilibrium, and any potential equilibrium must have $L = \bar{L}$. Clearly, if $L = \bar{L}$ in equilibrium, then the only quantity vector that would clear the market is $\mathbb{Q}$. Thus, the equilibrium quantity vector is unique.

Proof of Proposition 3

We will show that if $c(\bar{M} + \bar{L}) > r(\bar{L}) - 1$, then there exists a unique equilibrium $(\mathbb{Q}, \mathbb{R})$, where $L < \bar{L}$, $R^M = R^L = \bar{R}^M > R^D = R^B = \Pi$, $\frac{\delta L}{\delta M} < 0$, and $\frac{\delta \Pi}{\delta M} < 0$.

Consider L such that $c(\bar{M}+L) = r(L) - 1$. Such an L exists and is greater than zero by (A3). Since $c(\bar{M}+\bar{L}) > r(\bar{L}) - 1$, $L < \bar{L}$. This L is optimally demanded by both banks and firms when $R^D = \Pi$. Since $R^D = R^L - \left(\frac{R^L}{r(L)}\right)(c(\bar{M}+L)) < R^L$ for $L > 0$, we must have $R^M = \bar{R}^M = R^L > R^D = R^B = \Pi$. Now consider $\mathbb{Q} = (\bar{M}, L, L+\bar{M}, \bar{M}, \bar{B}-\bar{M}, W-(\bar{B}-\bar{M})-L)$. $\mathbb{Q}$ obviously clears the market at $R^M = \bar{R}^M = R^L > R^D = R^B = \Pi$. To see that $\mathbb{Q}$ is a unique quantity vector, it suffices to show that L is the only potential equilibrium loan quantity, for then market clearing would imply all other quantities would have to equate with $\mathbb{Q}$. Consider some $L^{'} \neq L$. $L^{'} > L$ would imply that $\Pi > R^D$ for $L^{'}$ to be optimal for both banks and firms, so $L^{'} > L$ cannot be an equilibrium. $L^{'} < L$ implies that $\Pi < R^D$ for $L^{'}$ to be optimal for both firms and banks. But this would imply that $S = 0$, and $L^{'}$ would not clear the market since $L^{'} < L < \bar{L}$. So $L^{'}$ cannot be an equilibrium loan quantity, and the only potential equilibrium loan quantity is L. Through implicit differentiation, we have $\frac{\delta L}{\delta M} = \frac{c^{'}(D)}{r^{'}(L)-c^{'}(D)} < 0$ by (A1). Similarly, we have $\frac{\delta \Pi}{\delta M} = \frac{[-R^L(c^{'}(D))(1+\frac{\delta L}{\delta M})]}{[1+c(D)]^2}$. Clearly, $\left|\frac{\delta L}{\delta M}\right| < 1$, so we have that $\frac{\delta \Pi}{\delta M} < 0$.

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Fedspeak: Who Moves U.S. Asset Prices?*

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This paper examines the financial market impact of different types of Federal Reserve communications on several U.S. asset prices (Treasury rates, stock prices, and the euro–U.S. dollar exchange rate) using an intraday event-study analysis. I construct a new database of over 2,200 Federal Reserve events for the period 2001–12. I document that some Federal Reserve events, such as the release of FOMC statements and minutes, the Chairman's semi-annual Monetary Policy Report to Congress, and his speeches, significantly increase both the volatility of U.S. asset prices and their trading volume. In contrast, speeches by the other members of the Board of Governors (including the Vice Chair) and by regional Federal Reserve Bank presidents do not significantly move U.S. asset prices. Finally, I find that, with the notable exception of FOMC statements, no other Federal Reserve event is associated with positive and statistically significant pre-announcement returns.

JEL Codes: C1, E5.

1. Introduction

Federal Reserve Chairman Bernanke's testimony to the Joint Economic Committee on the economic outlook on May 22, 2013 led to a large reaction in the Treasury market, with ten-year yields increasing roughly 10 basis points in the one hour bracketing the event. Market

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participants attributed this outsized market reaction to the Chairman's remark that "if we see continued improvement . . . in the next few meetings we could take a step down in our pace of purchases." Investors interpreted this comment as suggesting that the Federal Reserve might start to taper its monthly asset purchases sooner than expected. More generally, over the last decade central bank communication has become a key aspect of the Federal Reserve monetary policy. For instance, both Chairman Bernanke (2004a, 2004b) and Federal Reserve Vice Chair Yellen (2011, 2012, 2013) have said on a number of occasions that clear communication increases the effectiveness of monetary policy. Indeed, modern monetary theory (Woodford 2005) has highlighted the central role that the management of expectations about future interest rates has to enhance the effectiveness of policy. More recently, with short-term interest rates near the zero lower bound, communication about the future path of the target federal funds rate, so-called forward guidance, has become an essential part of unconventional policy (Woodford 2012).

The Federal Reserve uses many communication channels, including post-meeting statements, press conferences, minutes, testimonies, reports, and speeches. Extensive studies have documented the effect of the Federal Reserve's unanticipated target rate decisions on U.S. asset prices.[1] A recent strand of literature has also looked at the asset price response to the release of the Federal Open Market Committee (FOMC) statements.[2] Despite the vast and growing empirical evidence on the financial market effect of monetary news released on FOMC meeting days, little is known about the real-time (intraday) response of U.S. asset prices to other types of Federal Reserve communications, such as the information originating from Federal Reserve officials' speeches.[3] This article fills

[1]Some important studies include Kuttner (2001) and Fleming and Piazzesi (2005) for Treasury rates, Bernanke and Kuttner (2005) and Wongswan (2006) for stock prices, and Fatum and Scholnick (2008) for exchange rates.

[2]Gurkaynak, Sack, and Swanson (2005), Wongswan (2009), and Rosa (2011a, 2011b) document that both the surprise component of policy decisions and post-meeting statements have statistically significant and economically relevant effects on U.S. asset prices.

[3]Three recent contributions also look at the financial market impact of Federal Reserve communications, as I do in this paper. Ehrmann and Fratzscher

the gap by comparing the effectiveness of different types of Federal Reserve communications. Given the recent trend toward greater transparency (see, inter alia, Rudebusch and Williams 2008 and Middeldorp 2011, and the references therein), speeches by members of the Board of Governors (including the Chairman and the Vice Chair) and by regional Federal Reserve Bank presidents may provide salient insights into their views of the economic outlook and the likely course of future U.S. monetary policy. The extent to which market participants monitor, and respond to, these speeches to gain additional information beyond what is contained in the post-meeting statement is a question to be answered empirically. A challenge in addressing this question is, however, the large volume of FOMC talk. For instance, Federal Reserve officials gave 185 speeches in 2012 alone.

The contribution of this paper is twofold. First, a new database of over 2,200 (time-stamped) Federal Reserve events for the period 2001–12 is compiled. The database covers different types of Federal Reserve communications, including post-meeting statements, FOMC minutes, the Chairman's semi-annual monetary policy testimony, and Federal Reserve officials' speeches. Second, this study examines the financial market impact of different types of Federal Reserve communications on U.S. asset prices (two-year and ten-year Treasury rates, stock prices, and the euro–U.S. dollar exchange rate) using a high-frequency (five-minute) event-study analysis. The use of intraday data has the advantage of decreasing the likelihood that other market-relevant information is released during the narrow

(2007) and Hayo, Kutan, and Neuenkirch (2015) construct indicators of the tone in speeches and statements made by FOMC members. Then, they use a GARCH model with daily data to estimate the financial market impact of speeches delivered by FOMC announcements. Given the difficulty of quantifying the surprise component of central bank communications, Kohn and Sack (2004) study the effects of central bank communication events on the volatility of asset prices. This paper complements the findings of these works by using intraday, rather than daily, data. As discussed in the main text of the paper, the use of intraday data is important to precisely estimate the effect of Federal Reserve announcements. Moreover, this paper considers a more up-to-date sample period (from 2001 to 2012). This allows us to study not only the effect of new types of communication, such as the Chairman's press conference, but also the impact of Federal Reserve communication during the financial crisis (as opposed to normal times).

interval around the Federal Reserve event, thus increasing the confidence that any observed movement in asset prices is induced by the monetary policy news.

The main findings of the paper can be summarized as follows. First, I show that the Federal Reserve Chairman's speeches, as well as his semi-annual monetary policy testimony to Congress, induce "higher-than-normal" volatility across different asset classes. For instance, the volatility of two-year Treasury yields is roughly twice as large for the Chairman's speeches (four times as large for the testimony) at the time of the release compared with a period free of such an event. The magnitude of these effects is economically and statistically significant, and it is similar to the financial market impact of the FOMC minutes release, though smaller than the market impact induced by the release of the FOMC "balance-of-risks" statement. This finding implies that at least some part of the Chairman's speech or testimony carries an unanticipated component that affects asset prices. Second, other communications, such as speeches by the other members of the Board of Governors (including the Vice Chair) and by regional Federal Reserve Bank presidents, do not significantly move U.S. asset prices. Third, I examine the robustness of the above results along several dimensions. For instance, I carry out the analysis using trading volumes, and I redo the computations on different subsamples. This sensitivity analysis corroborates the core finding that the Chairman's speeches contain market-relevant information, especially for fixed-income securities. Finally, I test whether the pre-FOMC announcement drift documented by Lucca and Moench (2015), i.e., large average excess returns on U.S. equities in anticipation of monetary policy decisions made at scheduled FOMC meetings, holds for other types of Federal Reserve communications that also lead to increased volatility. I find that, with the notable exception of FOMC statements, none of the Federal Reserve events (including speeches by the Federal Reserve Chair) are associated with positive, large, and statistically significant pre-announcement returns.

The rest of the paper is organized as follows. Section 2 starts by describing the data set. Section 3 contains the discussion of the empirical results of the stock market reaction to the Federal Reserve's monetary policy. Section 4 examines the robustness of the results. Finally, section 5 concludes.

2. Data

I proceed by outlining the data for asset prices and Federal Reserve events—including FOMC statements, minutes, and Federal Reserve officials' speeches.

2.1 Asset Price Data

The high-frequency U.S. asset prices consist of quotes measured at five-minute intervals of on-the-run two-year and ten-year Treasury yields, futures prices on the S&P 500 stock index, and the euro–U.S. dollar exchange rate, covering the period 2001–12. Midpoints of bid/ask indicative quotes, observed at the end of each five-minute interval, are used to generate the series of (equally spaced) five-minute continuously compounded asset price returns.[4] If no indicative quote occurs in a given five-minute interval, I use the price from the previous interval (so-called previous tick rule in calendar time), as long as the previous price is quoted within the last thirty minutes. The Treasury bond yields are provided by Tradeweb and are based on indicative prices rather than transaction prices.[5] Hence, there is no associated volume data available. The S&P 500 futures data refer to the E-Mini S&P, a stock market index futures contract traded on the Chicago Mercantile Exchange's Globex electronic trading platform, and consist of both prices and trading volumes. A continuous series is constructed by considering the front-month contract and rolling over to the next contract on the expiration date. The front-month futures contract is defined as the nearest unexpired futures contract in the contract sequence (i.e., the shortest duration contract

[4]As noted by Andersen, Bollerslev, and Diebold (2007), the choice of five-minute sampling frequency is based on the balance between confounding market microstructure effects, such as the bid-ask bounce, staleness, and price discreteness, when sampling as finely as possible, and the loss of important information concerning fundamental price movements when sampling more coarsely. Note that Tradeweb data on Treasury yields start on November 13, 2001.

[5]When the quote is indicative, market participants are not obliged to trade at the price stated in the quote. The existing literature on exchange rates (e.g., Danielsson and Payne 2002 and Phylaktis and Chen 2009) has documented that indicative data bear no qualitative difference from those of transaction quotes. Reputation considerations tend to preclude the posting of prices at which a dealer would subsequently refuse to trade.

Table 1. Summary Statistics

	Two-Year Treasury	Ten-Year Treasury	S&P 500	EUR/$
Mean	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
Maximum	0.24	0.23	4.32	1.70
Minimum	−0.44	−0.31	−2.95	−2.22
Std. Dev.	0.01	0.00	0.08	0.04
Skewness	−1.33	−1.36	0.39	−0.24
Kurtosis	214	164	58	71
Jarque-Bera p-value	0.00	0.00	0.00	0.00
Observations	353,489	496,919	752,484	865,823

Notes: The table reports the summary statistics for the variables used in the econometric analysis. The sample period is January 2001–December 2012, excluding all weekend days. The asset price return is either the five-minute change in Treasury yields (measured in percentage terms), or the five-minute percentage change in the S&P 500 price, or the euro–U.S. dollar exchange rate. The euro–U.S. dollar exchange rate is defined as the U.S. dollar price of one euro such that a negative change implies an appreciation of the U.S. dollar.

that could be purchased in the futures market). The euro–U.S. dollar exchange rate data are provided by Electronic Broking System (in short EBS, now part of ICAP), and include trading volume in the global interdealer spot market (see Chaboud et al. 2004 for a detailed description of these data).[6] As noted by Chaboud, Chernenko, and Wright (2008), EBS and Reuters are two electronic broking systems that are used globally for interdealer spot trading. Trading in the euro–dollar and dollar–yen currency pairs is concentrated primarily on EBS. Throughout this paper, the euro–U.S. dollar exchange rate is defined as the U.S. dollar price of one euro such that a negative change implies an appreciation of the U.S. dollar.

Table 1 presents a selection of descriptive statistics for all the asset prices used in this paper, and reveals that the mean and the median of the five-minute Treasury yield changes, stock,

[6]The foreign exchange trading volume data are proprietary, and to preserve data confidentiality I show only relative volumes expressed in ratio form rather than as actual amounts of base currency.

and exchange rate returns is very close to zero. All returns are approximately symmetric, and all of them display excess kurtosis. The Jarque-Bera statistics strongly reject the null hypothesis that returns are normally distributed.

2.2 Federal Reserve Events

I create a database of over 2,200 Federal Reserve events for the sample period January 2001 to December 2012. The set of Federal Reserve events includes the release of FOMC statements, FOMC minutes, the Chairman's semi-annual monetary policy testimony before Congress (also known as the Monetary Policy Report, MPR), and speeches from members of the Board of Governors of the Federal Reserve and regional Federal Reserve Bank presidents. The list of these Federal Reserve events is obtained from the websites of the Federal Reserve Board (FRB) and the regional Federal Reserve Banks. I use Bloomberg to retrieve the time stamp of each Federal Reserve event.[7] To avoid double-counting, when an event is reported multiple times, I assign as release time its first occurrence. Then I apply a number of filters to clean the data. Specifically, I exclude an observation if (i) a speech occurs on weekends or outside standard U.S. trading hours (i.e., before 8 a.m. Eastern time, ET, or after 6 p.m. ET)[8] or (ii) a Federal Reserve event occurs at the same time as another Federal Reserve event. Federal Reserve Board members, as well as regional Federal Reserve Bank presidents, are often asked to testify to Congress on a number of topics, and give media interviews and academic presentations. The analysis of the financial market effect of these types of communications goes beyond the scope of this paper and is left for future research.

[7]In some occasions, Bloomberg does not report speeches by members of the Board of Governors and regional Federal Reserve Bank presidents. Since this study is primarily interested in estimating the financial market impact of the information that market participants receive, I am not very concerned about excluding speeches judged to be unnewsworthy by the newswire services.

[8]Since many important macroeconomic announcements are released at 8:30 a.m. ET (see, for instance, Faust and Wright 2011), to estimate the genuine effect of Federal Reserve events without any contamination from other sources, as a robustness check I also apply a stricter filter that excludes all Federal Reserve events that take place before 9 a.m. ET, rather than 8 a.m. ET. Importantly, all the results discussed below continue to hold.

Table 2 presents the distribution of Federal Reserve events over time. First, the FOMC schedules eight meetings per year, roughly every six weeks. These dates are set far in advance, and thus they can be viewed as exogenous and widely known. There are also additional unscheduled FOMC meetings, the timing of which arises endogenously. Since in the latter case the context of the rate decision is different, I analyze only scheduled meetings. The FOMC issues a policy statement following each regular meeting that summarizes the Committee's economic outlook and the policy decision at that meeting. Second, the FOMC minutes contain a more complete and nuanced discussion of the rationale for the Committee's decision and view of the risks to the outlook than was possible in the post-meeting announcement. Third, the Federal Reserve Act requires the Federal Reserve Board to submit semi-annually the Monetary Policy Report to the U.S. Congress. The report consists of two sections: the first summarizes past policy decisions, whereas the second describes recent financial and economic developments. Fourth, speeches by members of the Federal Reserve Board, as well as regional Federal Reserve Bank presidents, convey information about the current economic outlook and may serve to educate the public on a range of topics, including the central bank monetary policy strategy and the monetary transmission mechanism. In contrast to the FOMC statement, the content of the speeches is released to the media with an embargo time. In these occasions, newswire services can draft a set of news headlines that are released to the public simultaneously as soon as the embargo time has expired.

3. Results

3.1 Top Five Largest Moves in U.S. Asset Price around Federal Reserve Events

As a preliminary illustration of the relative importance of different types of Federal Reserve communications, I follow Fair (2002), and I review the largest asset price changes in a narrow window around each Federal Reserve event. The choice of the length of the window involves a trade-off. On the one side, using a narrow window decreases the likelihood that other relevant information is released in the market during the interval around the Federal Reserve event.

Table 2. Number of Monetary Policy Speeches per Year

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Count	Percent
FOMC Statement	8	8	8	8	8	8	8	8	8	8	8	8	96	4.3
FOMC Minutes	8	8	8	8	8	8	8	8	8	8	8	8	96	4.3
Testimony	2	2	2	2	2	2	2	2	2	2	2	2	24	1.1
Chairman	18	17	12	22	22	22	22	22	22	25	18	15	237	10.7
FRB Vice Chair	13	14	12	11	10	10	8	15	10	7	9	4	123	5.5
FRB Governors	23	32	34	60	45	37	36	30	18	23	19	19	376	16.9
Pres. Atlanta	4	3	7	5	6	5	4	14	12	12	22	13	107	4.8
Pres. Boston	4	5	6	1	2	3	4	10	10	7	12	10	74	3.3
Pres. Chicago	14	19	12	15	14	18	13	8	11	13	8	10	155	7.0
Pres. Cleveland	8	0	1	6	8	10	6	5	5	6	8	11	74	3.3
Pres. Dallas	8	5	2	4	7	20	18	13	15	11	16	11	130	5.8
Pres. Kansas City	3	0	3	2	3	4	2	4	11	9	7	2	50	2.2
Pres. Minneapolis	1	2	1	0	1	0	1	7	9	16	19	14	71	3.2
Pres. New York	3	6	2	8	9	10	9	3	9	14	19	16	108	4.9
Pres. Philadelphia	12	12	7	10	11	2	8	11	8	11	13	14	119	5.4
Pres. Richmond	3	0	9	3	8	10	9	8	13	13	12	10	98	4.4
Pres. S. Francisco	8	11	12	6	11	11	12	13	13	3	9	19	128	5.8
Pres. St. Louis	10	11	13	10	14	13	15	10	11	17	17	17	158	7.1
Total	150	155	151	181	189	193	185	191	195	205	226	203	2,224	100

Notes: The table reports the number of monetary policy speeches that have been included in the econometric analysis. The sample period is January 2001–December 2012. The column "Count" is the sum of the number of monetary events, and "Percent" is the ratio of that specific event over the total number of events.

On the other side, the cost is that the length of the window is not sufficient to capture the full effect of the Federal Reserve announcement. Considering this trade-off, to identify the top five largest price moves I choose a window that starts at the time of the release and ends ten minutes after.

Table 3 lists the top five largest moves in two-year and ten-year Treasury yields, S&P 500, and the euro–U.S. dollar exchange rate for the sample period 2001–12. Basis points are used to measure fixed-income moves, whereas percentage changes are used to gauge the scale of market moves in the equity and foreign exchange market. A number of interesting facts are apparent from the table. First, the FOMC rate decision and the related post-meeting statement cause most of the largest asset price changes (more than 80 percent of the changes). Moreover, the largest asset price responses are associated with the March 18, 2009 FOMC meeting, when the Federal Reserve announced multiple policy changes at the same time, including both its intention to keep the federal funds rate low "for an extended period" and its plans to extend asset purchases. The FOMC post-meeting statement released on January 28, 2004 also led to large changes in asset prices, with the two-year and ten-year Treasury yields jumping 23 and 19 basis points, respectively, in the ten minutes surrounding the release, and the U.S. dollar appreciating 0.7 percent against the euro. This large market response was induced not by an immediate change in the policy rate, but rather by an unanticipated change in the guidance regarding the target federal funds rate. On that day, in line with expectations, the FOMC left the target federal funds rate unchanged at 1 percent. Market participants were surprised, however, by changes to the wording of the statement with the removal of the "considerable period" phrase and the Committee stating instead that it could "be patient in removing its policy accommodation." The responses of asset prices suggest that market participants viewed the changing in the wording as steps toward the beginning of an eventual tightening cycle. This finding is consistent with the results of Gurkaynak, Sack, and Swanson (2005) and Rosa (2011a, 2011b) that both the surprise component of policy actions and official communication are important drivers of U.S. asset prices.

Second, roughly half of the largest asset price responses to Federal Reserve events took place between December 2007 and June

Table 3. Top Five Largest Changes in U.S. Asset Price Changes

A. Two-Year Treasury Rate			
Date	**Basis Point Change**	**Change in σ Units**	**Event**
01/28/2004 02:15 p.m.	23	38	FOMC Statement
01/11/2002 01:45 p.m.	−13	−15	Federal Reserve's Greenspan Speaks on U.S. Economy in San Francisco
03/21/2007 02:15 p.m.	−12	−14	FOMC Statement
12/16/2008 02:20 p.m.	−11	−9	FOMC Statement
09/18/2007 02:15 p.m.	−11	−13	FOMC Statement
B. Ten-Year Treasury Rate			
Date	**Basis Point Change**	**Change in σ Units**	**Event**
03/18/2009 02:15 p.m.	−30	−33	FOMC Statement
01/28/2004 02:15 p.m.	19	32	FOMC Statement
06/24/2009 02:15 p.m.	10	11	FOMC Statement
03/16/2004 02:15 p.m.	−9	−15	FOMC Statement
12/16/2008 02:20 p.m.	−8	−8	FOMC Statement
C. S&P 500			
Date	**% Change**	**Change in σ Units**	**Event**
03/18/2009 02:15 p.m.	2.4	12	FOMC Statement
12/11/2007 02:15 p.m.	−1.8	−15	FOMC Statement
10/03/2002 10:00 a.m.	1.2	6	Federal Reserve's Ferguson Speaks at SWIFT World Forum in Switzerland
01/30/2008 02:10 p.m.	1.2	4	FOMC Statement
10/29/2008 02:15 p.m.	−1.2	−4	FOMC Statement

(*continued*)

Table 3. (Continued)

D. EUR/$ Exchange Rate

Date	% Change	Change in σ Units	Event
03/18/2009 02:15 p.m.	1.4	18	FOMC Statement
12/16/2008 02:20 p.m.	0.7	8	FOMC Statement
01/28/2009 02:15 p.m.	−0.7	−9	FOMC Statement
02/11/2004 11:00 a.m.	0.7	12	Monetary Policy Report
01/28/2004 02:15 p.m.	−0.7	−12	FOMC Statement

E. Ten-Minute Volatility by Year

	Two-Year Treasury	Ten-Year Treasury	S&P 500	EUR/$
2001	1.3	1.2	0.18	0.07
2002	0.9	0.8	0.21	0.06
2003	0.7	0.8	0.14	0.07
2004	0.6	0.6	0.09	0.06
2005	0.5	0.5	0.09	0.05
2006	0.4	0.4	0.08	0.05
2007	0.9	0.6	0.12	0.04
2008	1.3	1.0	0.31	0.09
2009	0.7	0.9	0.20	0.08
2010	0.5	0.7	0.14	0.07
2011	0.5	0.8	0.16	0.07
2012	0.3	0.5	0.10	0.05

Notes: The table reports the top five largest asset price changes in a narrow window around the release of a Federal Reserve event. The sample period is January 2001–December 2012. The asset price return is either the ten-minute change in the bond yields (measured in basis points), or the ten-minute percentage change in the stock price, or the euro–U.S. dollar exchange rate. The event window starts at the time of the release and ends ten minutes after. The euro–U.S. dollar exchange rate is defined as the U.S. dollar price of one euro such that a negative change implies an appreciation of the U.S. dollar. The column "Change in σ Units" normalizes the asset price return by the respective year volatility. For completeness, panel E reports the volatility of ten-minute asset returns (between 9 a.m. and 4 p.m. ET, weekdays only) by year. Volatility is measured in basis points for Treasury rates and in percentage points for the S&P 500 and the euro–dollar exchange rate.

2009. Higher asset price volatility observed during the recent financial turbulence that started in August 2007 may explain part of this finding. In particular, panel E of table 3 displays the ten-minute volatility by calendar year, and indicates a higher-than-normal volatility in 2008. To allow meaningful comparisons across years, and thus to take into account the heteroskedasticity of asset returns, I normalize asset price moves by the corresponding ten-minute yearly volatility. The third column of panels A–D in table 3 shows that even in 2008 the largest price moves are between four and nine standard deviations away from the mean, suggesting that monetary news has remained an important driver of asset prices also during the financial crisis. A possible interpretation of this result is that in an environment of exceptional uncertainty, market participants may monitor even more closely the Federal Reserve monetary policy to gain additional insight into the future economic outlook and near-term interest rate decisions, and perhaps about the introduction of extraordinary liquidity facilities and the future asset purchases. Finally, among the top market movers, an important role seems to be played by the Federal Reserve Chairman through both speeches and his semi-annual testimony to Congress.

These examples underscore the importance of Federal Reserve communications in steering U.S. asset prices. In the next section, I turn to a more systematic analysis of the financial market impact of Federal Reserve events.

3.2 Volatility

A major challenge in estimating the financial market impact of central bank communications consists of quantifying the surprise component of the announcement, since there are no direct measures about market participants' expectations of the tone of Federal Reserve communications. Several authors (see, inter alia, Guthrie and Wright 2000; Romer and Romer 2004; Hayo, Kutan, and Neuenkirch 2015; and the references therein) have applied a narrative approach to overcome this issue. This procedure may, however, present some shortcomings, such as the inherent subjectivity of the classification of the tone of the announcement and the maintained assumption that central banks use code words in a consistent way. In this paper I follow Kohn and Sack (2004), and get around this difficulty by looking at the volatility of asset prices in a narrow window bracketing the Federal Reserve's release compared to non-event days. The underlying idea is that as long as some part of the policy release carries an unanticipated component, market participants revise to some extent their expectations, and the volatility of asset prices will be higher on announcement days than it would be otherwise. The reason to focus on volatility, rather than the level, of asset prices is that some speeches increase and others decrease prices, leaving the total net effect small relative to the absolute effect.

To gauge the extent to which Federal Reserve communications induce elevated price fluctuations, I look at (i) the standard deviation of the five-minute returns on release days, and (ii) the standard deviation of the five-minute returns on the same weekdays (of the previous and following week of the release day) and hours but on non-announcement days.[9] By doing so, I control for both intraday patterns and day-of-the-week effects, and thus I take into consideration that asset price volatility may be time varying. I consider the financial market impact induced by the release of the FOMC balance-of-risks statement, including the post-FOMC press conference, the FOMC minutes, and the semi-annual Monetary Policy Report to the U.S. Congress. I also consider speeches made by the Federal Reserve Chairman; the Vice Chair of the Federal Reserve Board; FRB Governors; the president of the Federal Reserve Bank of New York, who also serves as the vice chairman of the FOMC; and presidents of all the other regional Federal Reserve Banks.

Since asset price returns are not normally distributed, I use the Brown and Forsythe (1974) statistics to test the null hypothesis of equal variances in each subgroup. This statistical test is based on the absolute median difference and is robust under non-normality in the data, including the presence of fat tails, while retaining good statistical power. The sample period for all these events is January

[9] As a robustness check, I also consider the square root of the mean of squared returns, i.e., $\sqrt{\left(\sum_{t=1}^{T} r_t^2/(T-1)\right)}$, where r_t is the five-minute return, T is the number of observations in the sample, and the results (available upon request) remain extremely similar. As a further robustness check, I also compute the standard deviation of the five-minute returns on non-announcement days by using the previous and following day of the release date, rather than the same weekdays of the previous and following week of the release day. It is reassuring that the results reported in the paper continue to hold.

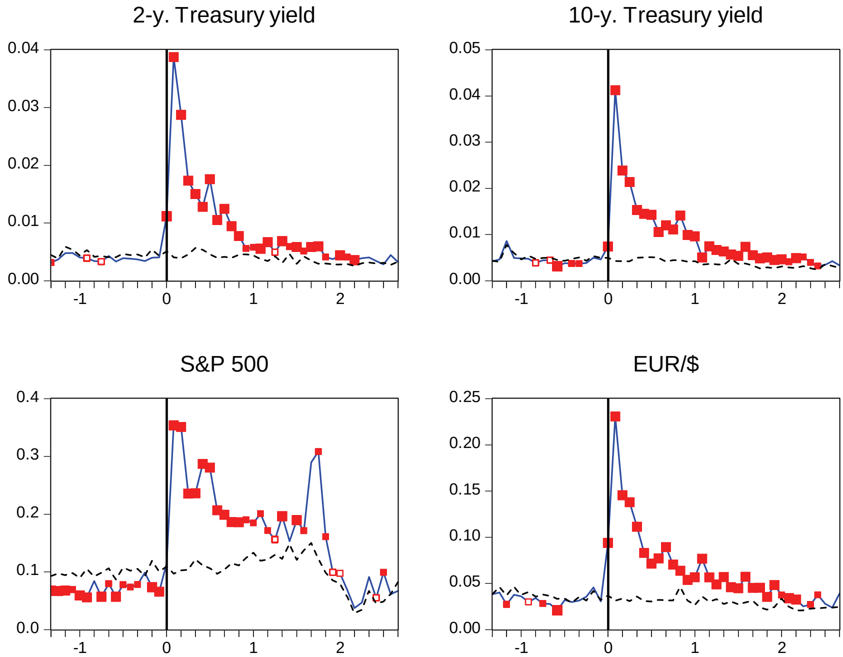
2001–December 2012, except for the FOMC minutes where, for institutional reasons explained below, I use the sample January 2005–December 2012. In the interest of space, most of these results can be found in a supplemental appendix at http://www.ijcb.org.[10]

Figure 1 displays the asset price volatilities on FOMC meeting days with a solid line from one hour before to two hours after the statement release time, indicated by a vertical line. A dashed line displays asset price volatilities on control days. Squares indicate the rejection of the null hypothesis: large and small filled squares denote significance at the two-sided 1 percent and 5 percent level, respectively, whereas a small hollow square denotes significance at the 10 percent level. The release of the FOMC post-meeting statement induces significantly higher-than-normal volatility on asset prices. For instance, the volatility of two-year Treasury yields suddenly jumps at the time of the release to about 4 basis points, roughly eight times larger on event days compared with a period free of such an event, and remains significantly higher up to around two hours after the event. Fixed-income assets are the most affected asset class, followed by the euro–U.S. dollar exchange rate and the S&P 500 stock prices. This result highlights the importance of FOMC announcements in driving U.S. asset prices.[11] Of note, the volatility of the S&P 500 is statistically lower in all of the five-minute periods leading up to the release of the FOMC statement. In other words, equity traders take a "wait-and-see" approach and restrain from transacting before the release of the statement. This *intraday* pre-announcement effect is consistent with the *daily* evidence documented by Bomfim (2003) that the stock market tends to be

[10]In future work, it would be interesting to separate speeches into those that focus on forward-looking monetary policy inclinations and the U.S. economic outlook as opposed to speeches that cover other topics, such as the regional economy, regulatory reforms, and commencement ceremonies.

[11]Chaboud et al. (2004), Fleming and Piazzesi (2005), and Rosa (2013), among others, report very similar results for the sample periods 1999–2004, 1994–2004, and 2005–11, respectively. Compared with those studies, this paper considers a more up-to-date sample period (2001–12). In contrast to Rosa (2013), this paper excludes unscheduled FOMC meetings in the set of event days. The timing of unscheduled meetings arises endogenously, instead of being set far in advance. Hence, the context of the rate decision is different compared with scheduled meetings. Note that the inclusion of unscheduled FOMC meetings tends to be associated with large asset price responses, especially for U.S. stock returns.

Figure 1. Volatility of Asset Prices around the Release of the FOMC Statement



Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release of the FOMC statement on FOMC meeting days with a solid line, and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the FOMC meeting day) with a dashed line. Returns are five-minute yield changes for Treasury rates and five-minute percentage changes for the S&P 500 and the euro–dollar exchange rate. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time of the FOMC minutes, i.e., 2 p.m. ET. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level respectively, whereas small hollow squares denote significance at the 10 percent level.

relatively quiet (i.e., conditional volatility is abnormally low) on days preceding regularly scheduled FOMC policy announcements.[12]

In April 2011 the Federal Reserve enhanced the transparency of its communication policy along two dimensions. First, the FOMC decided to release the Summary of Economic Projections (SEP) within hours of the meeting, rather than three weeks later with the release of the FOMC minutes. The economic projections are collected from each member of the Board of Governors and each Federal Reserve Bank president, and provide the policymakers' forecasts for a few economic variables (economic growth, unemployment, and headline and core inflation). The SEP has also included the projections for the future path of the target federal funds rate since January 2012. Second, the Federal Reserve joined several other central banks, such as the European Central Bank, the Bank of Japan, Sveriges Riksbank, and Norges Bank, in holding a post-FOMC meeting press conference. The goal of the press conference is to provide additional information to market participants beyond that contained in the monetary policy decision and post-FOMC statement. It comprises two elements: a prepared opening statement that typically contains a summary of the background considerations for the monetary policy decision, and a question-and-answer session, where financial journalists are given the opportunity to ask questions to the Chairman. To date, the entire press conference has lasted on average about one hour, of which roughly ten minutes have been devoted to the prepared remarks. Between June 2011 and December 2012, the timing of the events was as follows: the policy decision and the statement were released at 12:30 p.m. ET, the SEP was released at 2 p.m., and the press conference began at 2:15 p.m. Since the start of 2013, the Federal Reserve has changed the schedule of the events by releasing the statement and the SEP at 2 p.m. and starting the press conference at 2:30 p.m. The gap between the release of the decision from the release of the SEP and the accompanying press conference allows researchers to disentangle the financial market effect of each announcement separately. In other words, this work represents a first evaluation of the informational content of the SEP and the

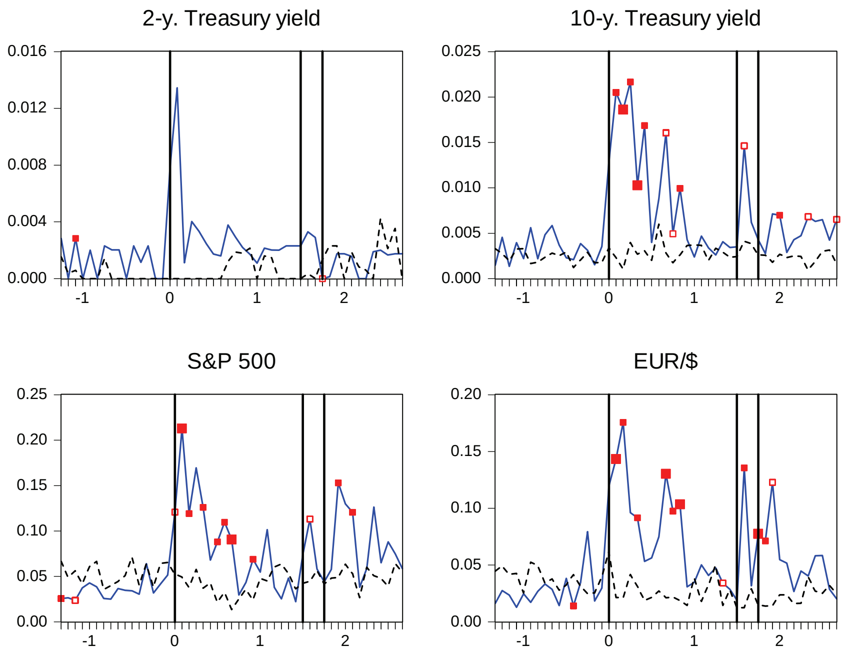
[12] Jones, Lamont, and Lumsdaine (1998) use daily data on Treasury securities for the sample 1979 to 1995, and document a similar "calm-before-the-storm" effect on days prior to important macroeconomic announcements.

Chairman's press conference as perceived by market participants.[13] Figure 2 displays the asset price volatilities on FOMC meeting days with a solid line and on control days with a dashed line. The vertical lines are placed at 12:30 p.m. (statement release time), 2 p.m. (SEP release time), and 2:15 p.m. (press conference start time). The sample period is January 2012–December 2012, since before 2012 the SEP did not contain the projections of the future path of the target federal funds rate. Given the small sample of press conferences that are analyzed (only five), the empirical results below should be interpreted cautiously. Consistent with the findings of figure 1, the release of the FOMC statement exerts an economically large and highly significant impact on U.S. asset prices, though its magnitude is roughly half the magnitude displayed in the period 2001–12. For instance, the average volatility at the time of the release of the ten-year Treasury yield is roughly 4 basis points in the whole sample period, and only 2 basis points in 2012. This finding is particularly accentuated for the two-year Treasury yields, which were strongly affected by the binding constraint of the zero lower bound (see also Swanson and Williams 2014 for a similar result). The novel feature of figure 2, however, is the assessment of the financial market impact of the release of the SEP and the press conference. The release of the SEP induces significantly higher-than-normal volatility on asset prices, especially on the ten-year Treasury yield and on the euro–dollar exchange rate. The press conference also adds additional information to the release of the FOMC statement and SEP, though to a lesser extent. These empirical findings confirm that the release of the SEP and the press conference are effective additional tools together with the statement in communicating in real time the Federal Reserve's views on the economic outlook and on the future path of the federal funds target rate.

Figure 3 displays the asset price volatilities on the release dates of the FOMC minutes. In this exercise the sample period starts in 2005; prior to that year, the minutes were released only after

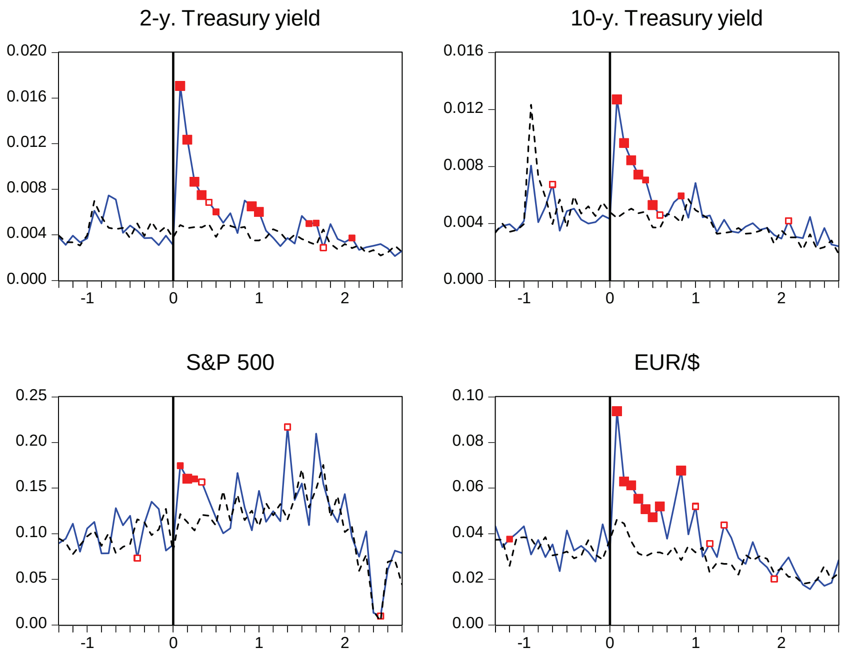
[13] A number of studies (Musard-Gies 2006; Rosa and Verga 2008; Ehrmann and Fratzscher 2009; Brand, Buncic, and Turunen 2010; and Conrad and Lamla 2010) have analyzed the impact of the European Central Bank's press conference on the European term structure and euro exchange rates, and document that the unexpected component of ECB communications has a significant and sizable impact on European asset prices.

Figure 2. Volatility of Asset Prices around the Release of the FOMC Statement, SEP, and the Chairman's Press Conference



Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the FOMC statement release with a solid line, and (ii) the standard deviation of five-minute asset price returns on control days (the same week-days and hours of the previous and following week of the FOMC minutes release day) with a dashed line. Returns are five-minute yield changes for Treasury rates and five-minute percentage changes for the S&P 500 and the euro–dollar exchange rate. The sample period is January 2012–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The first vertical line is placed at the release time of the FOMC statement (12:30 p.m. ET); the second vertical line is placed at the release time of the Summary of Economic Projections (2 p.m. ET); and the third vertical line is placed at the start of the Chairman's press conference (2:15 p.m. ET). Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

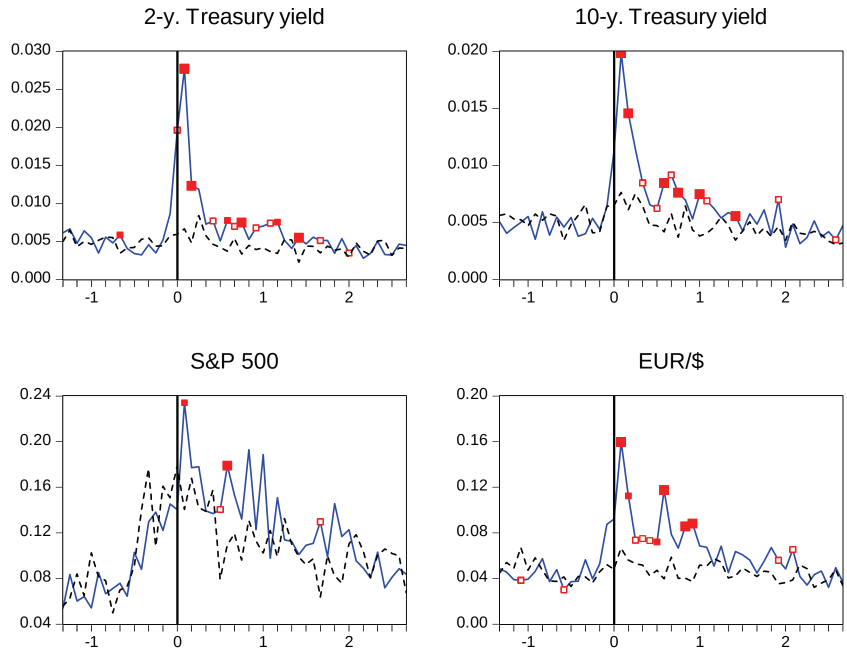
Figure 3. Volatility of Asset Prices around the Release of FOMC Minutes



Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the FOMC minutes release with a solid line, and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the FOMC minutes release day) with a dashed line. Returns are five-minute yield changes for Treasury rates and five-minute percentage changes for the S&P 500 and the euro–dollar exchange rate. The sample period is January 2005–March 2011. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time of the FOMC minutes, i.e., 2 p.m. ET. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

the next meeting had already finished, rendering them largely of historical interest. As documented in Rosa (2013), the release of the FOMC minutes increases volatility, especially for fixed-income assets. The reaction of asset prices is, however, less pronounced and

Figure 4. Volatility of Asset Prices around the Chairman's Testimony to Congress



Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the semi-annual Monetary Policy Report to Congress with a solid line, and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed line. Returns are five-minute yield changes for Treasury rates and five-minute percentage changes for the S&P 500 and the euro–dollar exchange rate. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

shorter lived than the market impact induced by the release of the FOMC statement.

Figure 4 displays the effect induced by the release of the Monetary Policy Report. The volatility of all asset prices, except stock prices, peaks at the time of the release and remains higher than normal for roughly one hour after the event. The economic importance of the MPR is similar to that of the minutes. For instance, the volatility of the ten-year Treasury yields around the release of the MPR and minutes is 2 and 1.6 basis points, respectively, versus a non-event volatility of half a basis point.

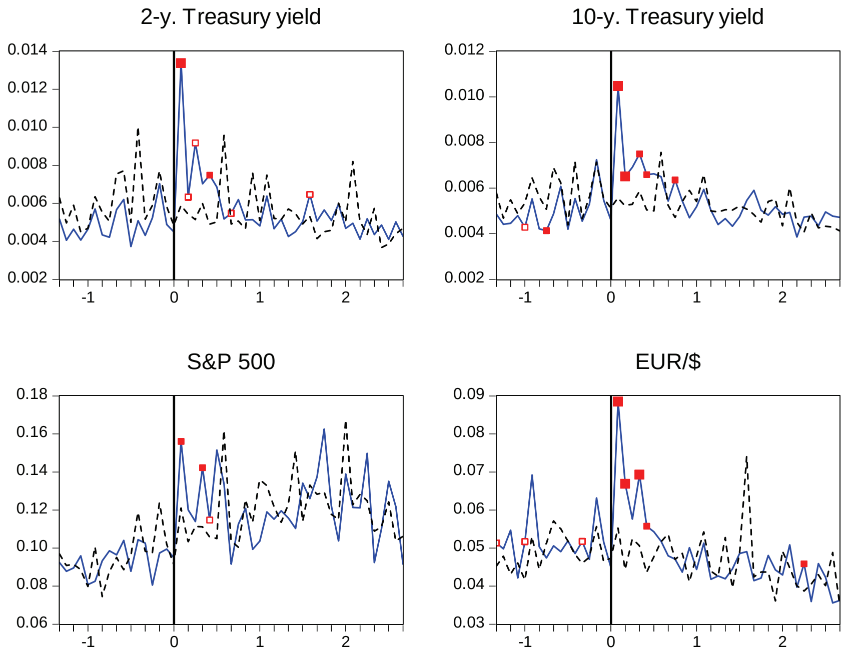
Another market-relevant Federal Reserve event is represented by the release of the Chairman's speeches. Figure 5 shows that the volatility of asset prices jumps at the time of the release and remains higher than normal for roughly thirty minutes after the event. Specifically, the volatility of Treasury yields becomes twice as large at the time of the release compared with non-announcement days. This finding indicates that the market effects of the Chairman's speeches are smaller than those induced by the minutes and the MPR.

Speeches by other Federal Reserve officials, including the Vice Chair of the Federal Reserve Board, FRB Governors, and presidents of the regional Federal Reserve Banks, are important as well, yet they do not as significantly affect the volatility of U.S. asset prices as those delivered by the Chairman (see figures 6–8). In other words, there are some notable speeches that seemed to substantially moved asset prices (e.g., on November 27, 2001, the two-year Treasury yield decreased roughly 20 basis points surrounding Governor Meyer's speech). However, on average the volatility of asset returns around the release of these speeches is not significantly different from the volatility on non-event days.

Finally, I look at the impact of speeches made by regional Reserve Bank presidents, distinguishing between voting and nonvoting members of the FOMC. Figure 9 and figure 10 show that on average the speeches of the regional Reserve Bank presidents seem to be significantly more effective in moving asset prices, and especially the two-year Treasury rate, when they serve as voting members, though the evidence is overall weak.

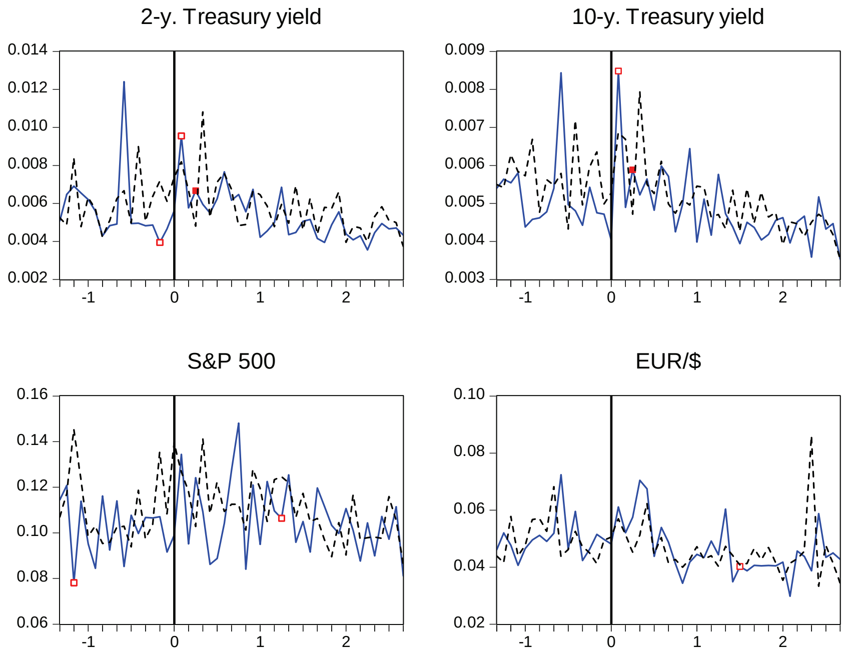
To sum up, this section shows that some Federal Reserve events, such as the release of FOMC statements and minutes, the Chairman's semi-annual Monetary Policy Report to Congress, and his speeches, significantly increase the volatility of U.S. asset prices. In contrast, speeches by the other members of the Board of Governors (including the Vice Chair) and by regional Federal Reserve Bank presidents do not significantly move U.S. asset prices.

Figure 5. Volatility of Asset Prices around the Federal Reserve Chairman's Speeches



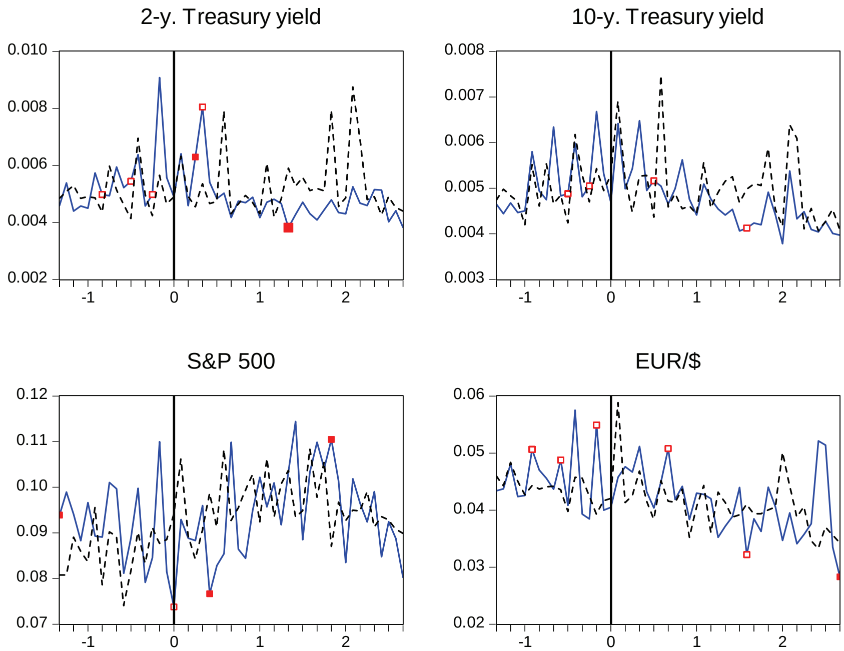
Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the speeches of the Federal Reserve Chairman with a solid line, and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed line. Returns are five-minute yield changes for Treasury rates and five-minute percentage changes for the S&P 500 and the euro–dollar exchange rate. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure 6. Volatility of Asset Prices around the FRB Vice Chair Speeches



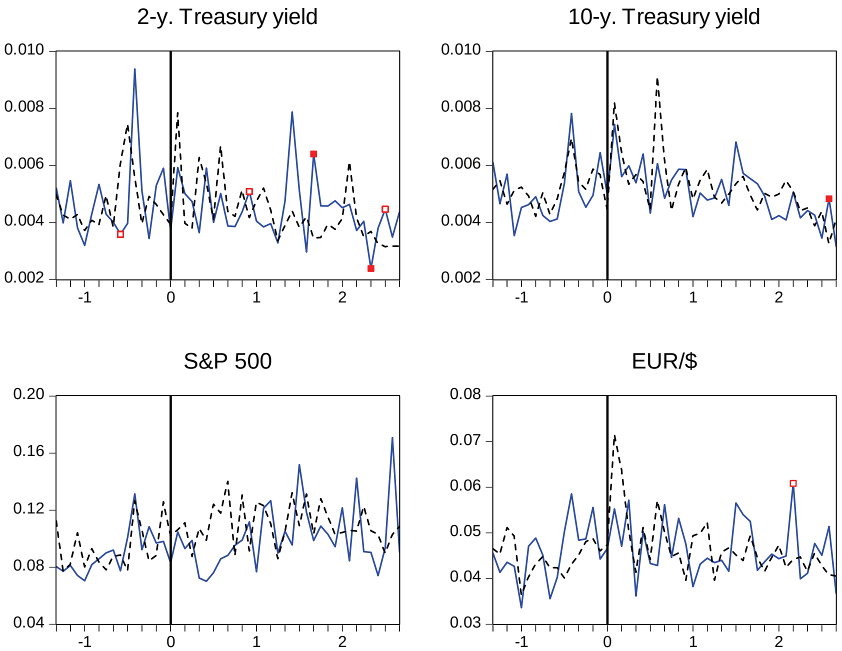
Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the speeches of the Federal Reserve Vice Chair with a solid line, and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure 7. Volatility of Asset Prices around the FRB Governors' Speeches



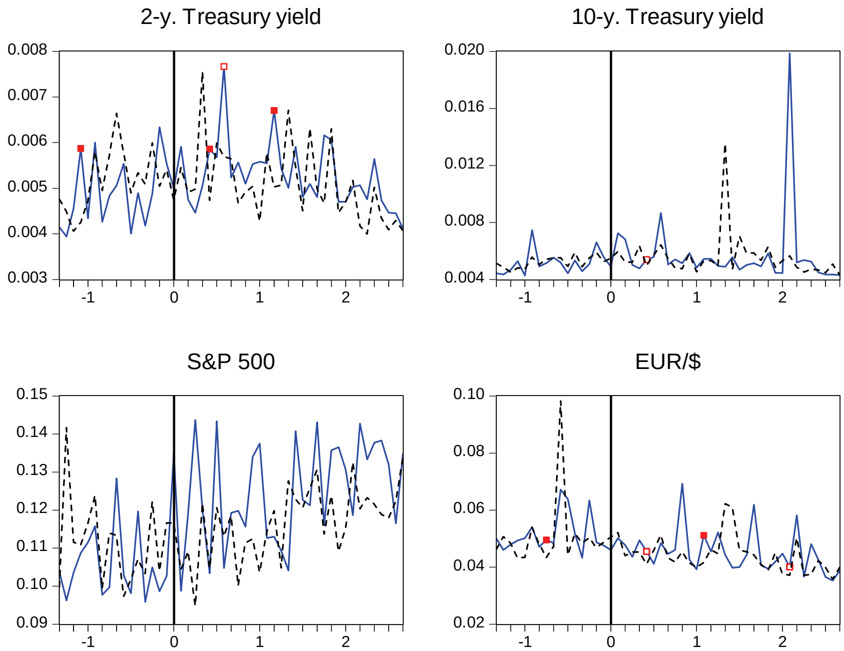
Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the speeches of the Federal Reserve Board Governors with a solid line, and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure 8. Volatility of Asset Prices around the Federal Reserve Bank of New York President's Speeches



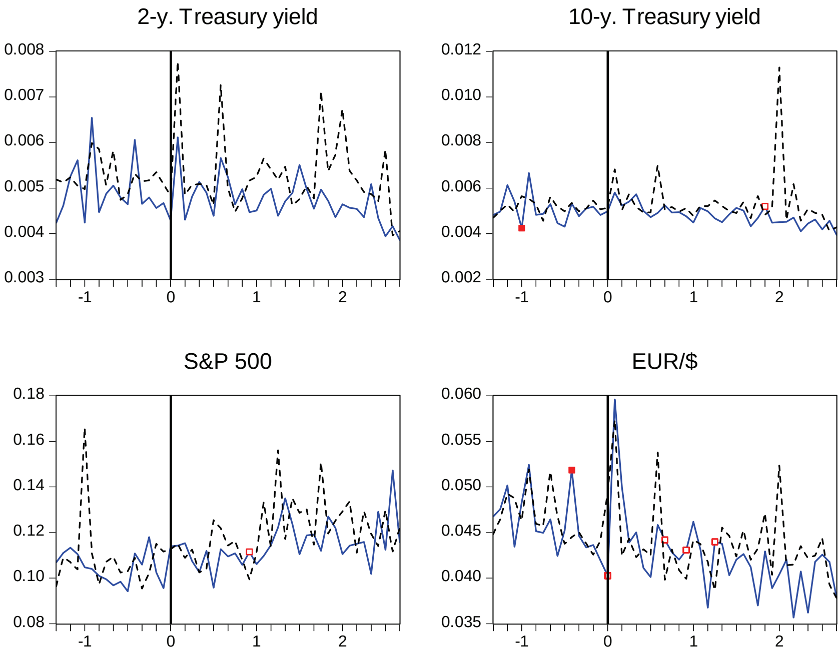
Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the speeches of the Federal Reserve Bank of New York president with a solid line, and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure 9. Volatility of Asset Prices around the Voting Regional Federal Reserve Bank Presidents' Speeches



Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the speeches of the voting presidents of the twelve District Federal Reserve Banks with a solid line, and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure 10. Volatility of Asset Prices around Speeches by Non-Voting Regional Federal Reserve Bank Presidents



Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the speeches of the non-voting regional Federal Reserve Bank presidents, who are also attend FOMC meetings, with a solid line, and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

3.3 Pre-announcement Drifts for Different Types of Federal Communications

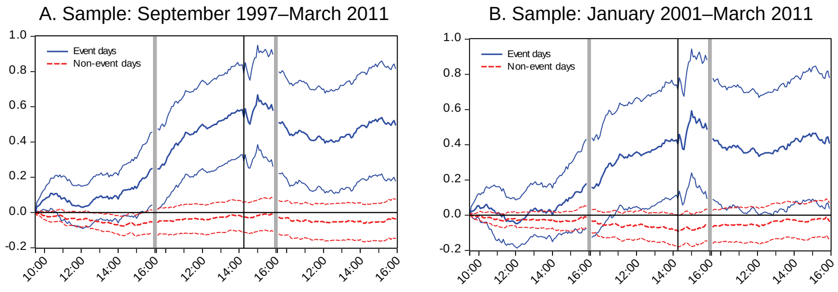
In this section, I test whether pre-announcement drifts are present not only for the release of FOMC statements but also for the release of other types of Federal Reserve communications.[14]

Savor and Wilson (2013) find positive and significant excess equity returns on days of inflation, labor market, and FOMC releases. Lucca and Moench (2015) extend this study by examining returns ahead of scheduled announcements, rather than unconditional returns on announcement days. They show that post-1994 stock returns have averaged about 0.5 percent from 2 p.m. of the day before to 2 p.m. ET of the day of scheduled FOMC announcements. Moreover, since 1994, more than 80 percent of the equity premium on U.S. stocks has been earned ahead of the FOMC announcement, and so it is not related to monetary policy decisions. I investigate whether the striking finding documented by Lucca and Moench (2015) holds (i) for the January 2001 to March 2011 period studied here, and (ii) for other types of Federal Reserve communications that lead to higher volatility. Figure 11 displays the average cumulative intraday returns on the S&P 500 stock prices over a three-day window from the market open of the day before to the day after FOMC meetings. The vertical line is set at 2:15 p.m. ET, when FOMC statements for scheduled meetings are released. The thick dashed line shows average cumulative returns on all other three-day windows that do not include FOMC announcements, whereas the thin (solid and dashed) lines represent 95 percent confidence bands around the average cumulative returns. Consistent with the findings of Lucca and Moench (2015), the figure displays a large and significant upward drift in the hours ahead of scheduled FOMC announcements over the sample September 1997 to March 2011 (chart in the left panel) and over January 2001 to March 2011 (chart in the right panel).[15] However, this pre-FOMC announcement drift is not present in other asset classes, such as the two-year and ten-year

[14] I thank an anonymous referee for suggesting this exercise.

[15] Since April 2011, the time of the release of the statement has varied between 12:30 p.m., 2 p.m., or 2:15 p.m., depending on whether the FOMC chairman holds a press conference.

Figure 11. Cumulative S&P 500 Returns: FOMC Statement (different samples)



Notes: Panel A displays the average cumulative returns on the S&P 500 stock prices on three-day windows. The five-minute asset return is the five-minute percentage changes for stock prices and the euro–dollar exchange rate. The five-minute returns are centered at zero. The sample period is from September 1997 to March 2011 (left panel) and January 2001 to March 2011 (right panel), and it includes only scheduled FOMC meetings. The thick solid line is the average cumulative return from 9:30 a.m. ET on days prior to 4 p.m. ET on days after scheduled FOMC announcements. The thick dashed line shows average cumulative returns on all other three-day windows that do not include FOMC announcements. The gray shaded areas are the end of the trading day. The thin lines represent 95 percent confidence bands around the average cumulative returns. The vertical line is set at 2:15 p.m. ET, when FOMC statements are typically released in this sample period.

Treasury rates and the euro–dollar exchange rate (results reported in a separate appendix).[16]

I further investigate whether U.S. asset prices feature abnormal returns ahead of other major Federal Reserve announcements. I consider scheduled Federal Reserve news, such as the release of the FOMC minutes and the release of the Monetary Policy Report, and speeches by Federal Reserve officials. For the FOMC minutes and the MPR, which are usually released at 2 p.m. ET and 10 a.m. ET, respectively, I compute average cumulative intraday returns from the market open of the day before to the day after the release of the Federal Reserve news. None of these two releases features statistically

[16]This pre-announcement drift is not present for other major central banks. Brusa, Savor, and Wilson (2015) find no significant effect for the policy announcements made by the Bank of England, the European Central Bank, and the Bank of Japan, either in their domestic stock market or in the U.S. stock market.

significant pre-announcement abnormal returns in the 2001–12 sample. Since the speeches by the Chairman, the Vice Chair, FRB Governors, and regional Federal Reserve Bank presidents may take place when U.S. financial markets are closed, I consider only speeches that occur between 8 a.m. and 5 p.m. ET. To assess the presence of abnormal returns I estimate the following regression:

$$R_t = \beta_0 + \beta_1 \mathbf{1}(\textit{pre-Fed event}_t) + \varepsilon_t, \tag{1}$$

where the dependent variable R_t stands for the twenty-four-hour U.S. Treasury yield changes, and the twenty-four-hour percentage change in the S&P 500 stock price and the euro–U.S. dollar exchange rate ending fifteen minutes before the event. The explanatory variable $\mathbf{1}(\textit{pre-Fed event}_t)$ is a dummy variable that equals one on pre-Federal Reserve announcement windows and zero otherwise. The error term represents other factors that affect asset prices on event times. The coefficient β_0 measures the unconditional average daily return earned outside of the pre-Federal Reserve event window, whereas the coefficient β_1 measures the unconditional average daily return differential earned on pre-Federal Reserve event days compared with other days. Estimation results (available in a separate appendix on the IJCB website) indicate that no Federal Reserve event other than the FOMC statement is associated with large and statistically significant pre-announcement returns.

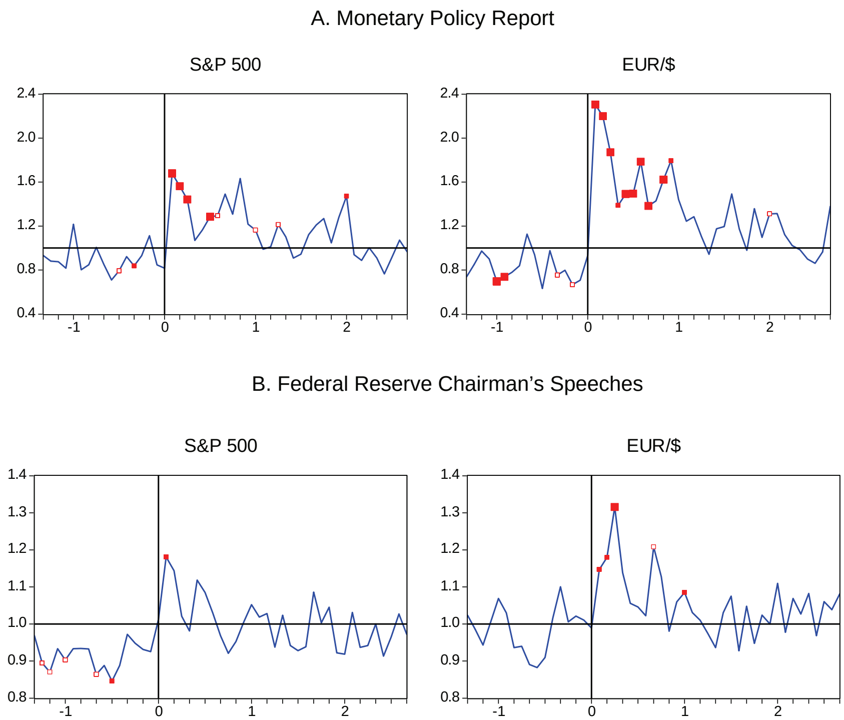
4. Robustness Checks and Extensions

To assess the robustness of the baseline results of the previous section, I also carry out the analysis using trading volumes for the S&P 500 stock index and the euro–U.S. dollar exchange rate, and I redo the estimations about the effect of the Chairman's speeches on different subsamples.

First, I look at the relationship between trading volumes and the arrival of Federal Reserve events. Since volumes have grown over time, to avoid overweighting the most recent years, I compute the ratio between (i) the five-minute volumes on release days, and the average of (ii) the five-minute volumes on the same weekdays (of the previous and following week of the release day) and hours but on non-announcement days. Then I test the null hypothesis that the median ratio equals one, i.e., the trading activity is the same on Federal Reserve event days and non-event days. The Wilcoxon signed-ranks test (see Newbold 1988) is employed to account for the possibility that the ratio is not normally distributed. Since the existing literature documents a positive contemporaneous relation between volume and volatility (see Karpoff 1987 and, more recently, Galati 2000), I expect that volumes are higher than normal around the release of Federal Reserve events. In the interest of brevity, I analyze only the market impact induced by the release of the Monetary Policy Report and the Chairman's speeches. Figure 12 (panel A) displays the effect induced by the release of the Monetary Policy Report. Trading activity is lower than normal before the release of the MPR, becomes twice as large as non-event days at the time of the release, and then gradually returns to its normal level. The response is more pronounced in terms of both magnitude and length for the euro–dollar exchange rates (at the peak 2.4 times as large as non-event days and the ratio is significantly different from one for roughly one hour after the event) than for the S&P 500 stock index (1.7 times as large and significantly different from one for about thirty minutes). Figure 12 (panel B) displays the effect induced by the release of the Chairman's speeches. On average, market activity is roughly 25 percent higher at the release time than non-event days for the S&P 500 and 20 percent higher for the euro–dollar exchange rates. To sum up, trading volumes around the release of the MPR and the Chairman's speeches follow a similar pattern exhibited by return volatilities. Specifically, trading volumes are higher on event days, and the difference of trading volumes between event and non-event dates peaks at announcement times.

Second, given the market impact of the Chairman's speeches, I investigate whether their effectiveness is affected by the identity of the Chairman by splitting the sample into two subsamples: January 2001–January 2006 (Chairman Greenspan) and February 2006–December 2012 (Chairman Bernanke). I find (results available in a separate appendix) that both Greenspan's and Bernanke's speeches move U.S. asset prices. However, speeches by Greenspan on average led to larger price movements in fixed-income assets than speeches by Bernanke. On average, the two-year and ten-year Treasury yields are roughly twice as volatile at the time of the release of a Greenspan speech compared with non-announcement

Figure 12. Trading Volumes around the Release of the Monetary Policy Report and the Federal Reserve Chairman's Speeches



Notes: This figure plots the median ratio between (i) volumes around the releases of the Monetary Policy Report and the Federal Reserve Chairman's speeches, and (ii) volumes on control days (the same weekdays and hours of the previous and following week of the event days). The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The sign test based on the normal approximation to the binomial distribution (Newbold 1988) is employed to test the null hypothesis that the median ratio between five-minute volumes in the two subgroups equals one. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

days, whereas they are just 1.3 times as volatile at the release time of a Bernanke speech. Stock prices react relatively more to speeches by Bernanke than to speeches by Greenspan, whereas the response of the euro–dollar exchange rate is similar across the speeches by either Chairman.

Third, I investigate whether the recent financial crisis has changed the importance of Chairman Bernanke's speeches by splitting the sample into two subsamples, February 2006–December 2007 (pre-crisis) and January 2008–December 2012 (during the crisis). The financial market turmoil that erupted in August 2007 led to the most severe financial crisis since the Great Depression. The financial turbulence in the subprime mortgage market rapidly spread to money markets. The Federal Reserve responded aggressively by using conventional and unconventional policies. On the one hand, the Federal Reserve implemented a number of programs designed to support the liquidity of financial institutions and foster improved conditions in financial markets. On the other hand, the Federal Reserve also lowered the target federal funds rate from 5.25 percent to effectively zero in the midst of the worst recession since the Great Depression. Despite reaching the zero lower bound on its main operating instrument, the Federal Reserve was able to further ease financial conditions by implementing large-scale asset purchase programs. In this rapidly changing environment, characterized by heightened uncertainty and where extreme tail risks have become elevated, I expect that market participants pay more attention to any central bank announcement compared with a pre-crisis period. Estimation results (available in a separate appendix) confirm that Bernanke's speeches are much more important in the period 2008–12 than in the earlier 2006–07 period. More specifically, Bernanke's speeches do not induce higher-than-normal volatility in the pre-crisis period, whereas they strongly move U.S. asset prices during the crisis. For instance, at the time of the release, both the ten-year Treasury yield and the euro–dollar exchange rate are roughly twice as volatile as on non-event days in the latter sample period.

5. Conclusions

This paper examines and compares the financial market impact of different types of Federal Reserve communications on U.S. asset prices using an intraday event-study analysis. This relationship is an important topic for several reasons. From a central banking perspective, this line of research sheds further light on the monetary policy transmission mechanism. The large amount of private-sector resources devoted to monitoring and forecasting U.S. monetary policy suggests that market participants are equally interested in this topic, and in particular in determining which of the Federal Reserve officials has on average the largest impact on U.S. asset prices. As stated above, while the impact of monetary policy decisions and post-meeting statements on asset prices has been well documented, relatively little is known about the effect of a broader set of Federal Reserve announcements. This paper fills this gap by constructing a new database of over 2,200 (time-stamped) Federal Reserve events for the period 2001–12. This study documents that some Federal Reserve events, such as the release of FOMC statements and minutes, the Chairman's speeches, and his semi-annual Monetary Policy Report to Congress, significantly affect both the volatility of U.S. asset prices and their trading volume. In contrast, speeches by the other members of the Board of Governors (including the Vice Chair) and by regional Federal Reserve Bank presidents do not significantly move U.S. asset prices. Finally, I find that, with the notable exception of FOMC statements, no other Federal Reserve event is associated with positive and statistically significant pre-announcement returns.

The findings of this paper have important implications. Central banks may use these results to identify the best approaches in designing their communication strategy. For instance, since most of the price action takes place at the time of the release of the speech, particular care should be taken in drafting the executive summary of the Federal Reserve officials' speeches. From the perspective of financial market participants, it is important to identify the set of events that systematically move asset prices. Having estimates of the responsiveness of U.S. asset prices to some monetary policy events, such as the Chairman's speeches and his semi-annual monetary policy testimony to Congress, is an important input in formulating effective trading and hedging strategies and portfolio allocation decisions.

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Globalization, Pass-Through, and Inflation Dynamics*

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An important aspect of the globalization process is the increase in interdependence among countries through the deepening of trade linkages. This process should increase competition in each destination market and change the pricing behavior of firms. We present an extension of Dornbusch's (1987) model to analyze the extent to which globalization, interpreted as an increase in the number of foreign products in each destination market, modifies the slope and the position of the New Keynesian aggregate supply equation and, at the same time, affects the degree of exchange rate pass-through. We provide empirical evidence supporting the implications of our model.

JEL Codes: F40, F60.

1. Introduction

The increased interdependence among countries through the deepening of trade linkages in goods and financial assets, spurred by the so-called process of globalization, has attracted the attention of economists and policymakers. One important theme, which has been the subject of considerable discussion, has been the "global slack"

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hypothesis, namely the increased dependence of inflation dynamics on global factors rather than just on domestic economic activity.[1]

This paper focuses on two channels through which firms' globalization affects inflation dynamics. First, we ask how globalization, interpreted as an increase in the share of goods sold by foreign firms in the domestic market, affects the dynamic of imported inflation through its influence on the pass-through of exchange rate into import prices. The second channel through which globalization influences the dynamic of inflation occurs, indirectly, through its effect on the pricing strategies and the degree of competition of domestic firms selling in the domestic market. We show that this channel changes the slope and the position of the New Keynesian aggregate supply equation.

To address these issues we extend Dornbusch's (1987) model to a dynamic context with price stickiness. Domestic and foreign firms compete in a strategic way to increase their market shares via their pricing decisions. In this context, the price markup becomes a function of each firm's market share, which in turn is a function of competitors' prices and marginal costs. Hence domestic and foreign marginal costs affect each other through their influence on firms' market shares and markups.

We study the implications of this model for the exchange rate pass-through and the dynamic of prices set by foreign and domestic firms in the domestic market.

On the one side, we show that the degree of exchange rate pass-through depends upon the share of foreign products in the market and upon the degree of market concentration. Greater competition, due to the increase in the share of foreign products sold in a specific industry—a phenomenon strongly connected with globalization—raises the degree of exchange rate pass-through, both in the short and in the long run. Through this channel, globalization amplifies the dependence of imported good inflation upon external conditions. Our theoretical results are confirmed through an empirical analysis based on sectors belonging to the harmonized system (HS) classification. Changes in import prices for a number of sectors are regressed on past changes in the same prices and on current and past changes

[1] See, among others, Bernanke (2007), Borio and Filardo (2006), Fisher (2006), and Rogoff (2003).

of the effective exchange rate. By using alternative tests to identify the intensification of the globalization process, we repeat estimations on the data samples before and after the break points, showing an increase of pass-through in at least half of the sectors considered. To deepen the assessment of the role of competition and foreign firm penetration, we regress the pass-through coefficient, estimated via rolling-window samples, over an index of foreign firms' market penetration, which we proxy with the share of imports from China over total imports. Further robustness of the penetration index is assessed by subsequently adding the Herfindhal concentration index in the regression. We find that an increase in the penetration index increases pass-through and the relation is statistically significant.

Our framework also has important implications for the reduced form of the New Keynesian Phillips curve. The Phillips curve of our model is augmented by a link between domestic inflation and the market share of domestic firms, with the latter proxied by the relative price of foreign versus domestic products. This channel reflects the strategic competition in pricing between domestic and foreign firms, which influences directly the inflation dynamic of domestic firms, even when domestic marginal costs do not vary. The presence of foreign prices in the new augmented Phillips curve creates a link between domestic inflation and foreign marginal costs, which in turn is connected to the foreign output gap. This is the essence of the "global slack" hypothesis.

In traditional open-economy models, domestic real marginal costs are affected by terms of trade (see Benigno and Benigno 2008), which can shift the Phillips curve for a given domestic output gap. This channel runs as follows. When foreign prices decrease and terms of trade improve, there are inflationary pressures on domestic prices. This shifts the Phillips curve upward. Woodford (2007) pointed out that such a shift is actually at odds with the conventional view regarding the effects of globalization on inflation dynamics. The *relative price* channel emphasized by our model can rationalize common wisdom, as an increase in the share of imports moves the Phillips curve consistently with the global slack hypothesis: downward (upward) when foreign prices decrease (increase). In addition, we show that the degree of market concentration also influences the slope of the Phillips curve, namely the sensitivity of inflation to marginal costs. Higher competition, captured by a higher number of firms in the market, steepens the Phillips curve, implying that domestic prices become more sensitive to domestic marginal costs.

We provide support for the relative price channel by estimating the reduced-form Phillips curve implied by our model. We use U.S. data for the non-farm business sector and the manufacturing sector and compare the estimation's results across the two sectors. There are two main results. First, the relative price channel is crucial in improving the fit and the estimates of the traditional aggregate supply (AS) curve. The literature has already discussed the difficulties for the estimates of the traditional Phillips curve to deliver robust and significant results (most notably Fuhrer 2009): our relative price channel can provide one of the missing links. Second, and consistently with the model, we find that the relative price channel is stronger in the second part of the sample, after 1999, which coincides with the pickup of trade globalization.

The rest of the paper proceeds as follows. Section 2 discusses the relation of our paper with the most recent literature on the effects of globalization on inflation dynamics and pass-through. Section 3 shows the model. Section 4 solves the model under flexible prices. Section 5 solves the model under sticky prices. Section 6 discusses the empirical analysis on the exchange rate pass-through and that on the estimation of the New Keynesian AS equation with our new channel. Section 7 concludes.

2. Comparison with the Literature

Our paper is related to an extensive literature which has assessed the degree of exchange rate pass-through (see Goldberg and Knetter 1997 for a seminal contribution) and to a more recent literature studying the impact of globalization on inflation dynamics.

We base our analysis on a model presented by Dornbusch (1987) which, to our knowledge, is the first example of a Dixit-Stiglitz model of imperfect competition extended to include strategic interaction among firms. Dornbusch (1987) already derives a relationship between prices and marginal costs based on a non-constant markup, showing that it depends on the strategic interaction between firms. He also discusses the possibility that exchange rate pass-through can be imperfect. In this respect, our contribution is to analyze more deeply, using log-linear approximations, the relationship between industry prices and exchange rates and relate it to the market size, the share of competing foreign firms, and to the elasticities of substitution across goods within and across industries. Of course, our model shares similar features with other models of imperfect competition built on Dornbusch (1987), like Atkeson and Burstein (2008), who study fluctuations in relative purchasing power parity. However, in the latter work, firms compete on quantities rather than on prices, unlike our model.[2] In a contemporaneous work, Auer and Schoenle (2012) have also used strategic pricing in a model à la Dornbusch (1987) and derived a similar relationship between pass-through and firms' market share.[3] Their focus is not on the impact of globalization on the exchange rate pass-through. However, they investigate more deeply the empirical implications of the theory along several dimensions that we do not explore in our work, including the cross-sectional price distribution among firms. The competitive effect of globalization discussed in our model resembles that explored by Chen, Imbs, and Scott (2009), who follow Melitz and Ottaviano (2008). The latter work shows that greater competition by foreign firms and an increased share of imports induce a fall in profit margins and markups. The important difference is that firms' heterogeneity is not essential in our framework, as the competitive effect is determined by the strategic interaction among firms. The role of market competition is also considered from a different angle in Bodnar, Dumas, and Marston (2002), who focus on the relationship between the exposure of firms' profits to exchange rate fluctuations and the exchange rate pass-through. Finally, there is a related extensive literature which has studied alternative ways to capture imperfect pass-through of marginal costs to prices. Rotemberg and Woodford (1992) also adopt a collusive oligopolistic market structure to derive a non-constant markup model showing that in this case the markup can be a function of the industry's expected profits. Ravn, Schmitt-Grohe, and Uribe (2010, 2012) exploit preferences displaying deep habits to build a dynamic demand function, which also features an imperfect pass-through of costs into prices. Gopinath and

[2]Soto and Selaive (2003) develop a general equilibrium model of oligopolistic competition in which firms compete on quantities rather than on prices.

[3]The link between exchange rate pass-through and market share has originally been discussed and tested by Feenstra, Gagnon, and Knetter (1996), who show that pass-through should be high for exporters with large market shares.

Itskhoki (2007) and Gust, Leduc, and Vigfusson (2010) use instead a non-isoelastic demand function in line with Kimball's (1995) preferences. In contrast to our findings, Gust, Leduc, and Vigfusson (2010) argue that trade integration has led to a decline in exchange rate pass-through. As proxies of trade integration, they use the fall of an iceberg trading cost faced by foreign firms and the increase in their productivity. However, market size and shares remain invariant in their model. Instead, our focus is on how changes in the market composition and size directly affect pass-through without tracing them back to their determinants.

One further contribution of our paper is to extend the imperfect-competition model of Dornbusch (1987) to a dynamic context with price frictions. Our model delivers a New Keynesian AS equation suitable to analyze the impact of globalization on inflation dynamics. In this respect, our approach competes with a recent literature addressing the same theme but using different features. Sbordone (2007) exploits Kimball's (1995) preferences to introduce time-varying demand elasticities into a closed-economy model with a standard Calvo (1983) pricing mechanism. She finds that the relation between trade globalization (modeled as an increase in the number of varieties) and the slope of the Phillips curve changes depending on the parameters' configuration. Guerrieri, Gust, and Lopez-Salido (2010) apply Kimball's (1995) preferences to an open-economy model and derive a reduced New Keynesian Phillips curve, in which domestic inflation (but not the slope of the Phillips curve) also depends on the ratio between prices of imported goods and domestic prices. Our model delivers a similar New Keynesian Phillips curve but based on specific microfoundations which capture firms' strategic behavior and therefore imply different relationships between the parameters of the curve and indexes of international competition.

We use our theoretical model to derive two sets of empirical implications that we test. Globalization, which is proxied by a higher share of foreign firms in the domestic market, should imply an increase in the degree of exchange rate pass-through and shifts of the domestic AS equations mainly driven by movements in the relative price of foreign with respect to domestic goods.

To test the first implication, we use U.S. sectoral import prices taken from the Bureau of Labor Statistics (BLS) and corresponding to the one-digit harmonized system classification. Results on the direction of pass-through are mixed but show, for a significant number of sectors, evidence supporting our theoretical results. The extensive empirical literature on the argument shares the ambiguity of our results. Campa and Goldberg (2005) find a weak tendency toward a decline in exchange rate pass-through rates which is statistically significant for only four out of twenty-three OECD countries, albeit not for the United States. Campa and Goldberg (2008) also find mixed evidence: by examining pass-through of exchange rate movements into import prices of manufacturing sectors of OECD countries, they indeed uncover cases in which it has increased and cases in which it has decreased.[4] Marazzi and Sheets (2007) instead find compelling evidence for a declining exchange rate pass-through to an aggregate index of U.S. import prices.[5] In comparison with Campa and Goldberg (2005, 2008), they argue that the inclusion in the regression of a control for movements in oil and other commodity prices is critical for the result. We work with relatively more disaggregated data than Marazzi and Sheets (2007) and also test our implications by including a measure of commodity prices in line with their suggestion. In this case, the number of sectors in which we find an increased pass-through is lower, but we still find an overall balance between increasing and decreasing cases.

Finally, the analysis of the impact of globalization on the AS equation confirms the findings of Guerrieri, Gust, and Lopez-Salido (2010) showing that the relative price of foreign with respect to domestic goods is a significant variable to include in order to explain inflation dynamics. As a price index, we use BLS data on the nonfarm business sector and the manufacturing sector, while they use a tradable goods price index. Moreover, in line with our theoretical implications, we show that the additional open-economy variable is more relevant in the last part of our sample, therefore capturing the effects of globalization on domestic inflation dynamic.

3. A Model of International Strategic Pricing

We analyze a two-country model in which the home economy is indexed by h and the foreign economy by f. In each economy there

[4]Their data set covers the period 1976–2004. The break is placed in 1995.

[5]Gust, Leduc, and Vigfusson (2010) also discuss some evidence for a decline in pass-through in a data set that includes forty finished goods industries.

are multiple sectors, indexed by k. In each sector of the home country, there are N differentiated goods, of which N_h are produced by firms residing in country h and the remaining N_f by firms residing in country f. Similarly, in country f there are N^* differentiated goods, of which N_h^* are produced by firms residing in country h and N_f^* by firms residing in country f. Assuming that in each sector individual varieties are aggregated according to a Dixit-Stiglitz aggregator, optimal demand of a generic good i, produced in country h and belonging to a sector k, is given by

$$Y_i = \left(\frac{P_i}{P_k}\right)^{-\sigma} \left(\frac{P_k}{P}\right)^{-\theta} Y, \tag{1}$$

where σ is the elasticity of substitution among different varieties produced in the generic sector k and θ is the elasticity of substitution across sectors. We define the overall demand in the economy, Y, the economy-wide price index, P, the price of good i, P_i, and the aggregate price of the sector k, P_k, with the latter given by

$$P_k = \left(\sum_{i=1}^{N_h} P_i^{1-\sigma} + \sum_{j=1}^{N_f} P_j^{1-\sigma}\right)^{\frac{1}{1-\sigma}}, \tag{2}$$

where P_j denotes the price of a generic good j in the sector k, produced in country f.

Following Dornbusch (1987), we assume that firms are not small with respect to their sector, meaning that in their pricing decisions, they internalize the fact that they can influence the sectoral price. The elasticity of demand of good i with respect to its price P_i is not necessarily constant and is instead given by

$$\frac{\partial Y_i}{\partial P_i}\frac{P_i}{Y_i} = -\sigma + \sigma\frac{P_i}{P_k}\frac{\partial P_k}{\partial P_i} - \theta\frac{P_i}{P_k}\frac{\partial P_k}{\partial P_i}, \tag{3}$$

which can be written in a more compact form, and in absolute value, as

$$\tilde{\sigma}_i \equiv \left|\frac{\partial Y_i}{\partial P_i}\frac{P_i}{Y_i}\right| = \sigma - (\sigma - \theta)\xi_i, \tag{4}$$

where ξ_i identifies the market share of firm i in sector k given by

$$\xi_i \equiv \frac{P_i Y_i}{P_k Y_k} = \frac{P_i}{P_k}\frac{\partial P_k}{\partial P_i}. \tag{5}$$

The elasticity of demand faced by the generic firm i, $\tilde{\sigma}_i$, boils down to that of monopolistic competition under two cases. The first occurs when all firms are small, i.e., when their market share goes to zero, $\xi_i \to 0$. The second case occurs when the demand elasticity across different varieties and that across different sectors coincide, $\theta = \sigma$; under this condition firms do not have leverage in affecting sectoral aggregate prices. The empirically relevant case is the one in which the elasticity across different varieties, within a single sector, is higher than that across sectors, implying a $\tilde{\sigma}_i$ which is a decreasing function of firm's i market share. In the limiting case where there is only one firm i in each sector, we can obtain that $\tilde{\sigma}_i = \theta$. Intuitively, monopoly power rises with the market share.

The equilibrium is symmetric since all firms in a sector face the same technology and optimization problem. Therefore we drop the index i. The market share of firms based in country h is then given by

$$\xi_i = \xi_h = \frac{P_h Y_h}{N_h P_h Y_h + N_f P_f Y_f}, \tag{6}$$

where P_h, P_f, Y_h, and Y_f are prices and output in country h for firms resident in country h and f, respectively.

Our model implies that variation in the market share causes changes in the markup. Since relative prices influence the market shares, firms internalize the impact of their pricing decisions on the overall market equilibrium. An important implication is that prices become more sensitive to other firms' marginal costs and, with international competition, to exchange rate fluctuations. We label this channel the pro-competitive effect since it echoes the ones analyzed in Chen, Imbs, and Scott (2009), Ghironi and Melitz (2005), and Melitz and Ottaviano (2008) in models that allow for firm heterogeneity. Notice that this pro-competitive channel survives in our model even in the absence of firm heterogeneity because of strategic pricing competition.

As mentioned earlier, we focus on one aspect of the globalization process, namely the increase in the number of foreign products in the domestic market. Such an increase reduces the market share of both domestic and foreign firms, and therefore increases the elasticity $\tilde{\sigma}_i$ and reduces the monopoly power. First, we study the model's implications for the sensitivity of prices to marginal costs and, in particular, we analyze the degree of exchange rate pass-through, when prices are fully flexible. Later, we introduce sticky prices.

It is useful to question why the possibility of rent extraction is not caught by domestic firms prior to the entrance of foreign firms. The fundamental explanation would rest on comparative advantage and efficiencies of foreign firms. It might well be that wages in the foreign country are too low or technological innovations spanning the whole range of tastes in the constant elasticity of substitution (CES) aggregator only happen to realize through foreign firms. We do not model these comparative advantages, but rather take them as granted within the framework of our partial equilibrium analysis.

4. Flexible Prices

Under flexible prices, a firm i, producing and selling in country h, chooses P_i to maximize the following profit function:

$$\Pi_{i,t} = P_{i,t} Y_{i,t} - \frac{W_t}{A_t} Y_{i,t}, \tag{7}$$

under the demand function (1), where W_t are nominal wages in the labor market of country h and A_t denotes a common productivity shifter in country h. The production function is assumed to be linear in labor, the only factor of production.

Standard optimization implies the following first-order condition:

$$P_{i,t} = \frac{\tilde{\sigma}_{i,t}}{\tilde{\sigma}_{i,t} - 1} \frac{W_t}{A_t}, \tag{8}$$

showing that prices are set as a time-varying markup over marginal costs, where $\tilde{\sigma}_{i,t}$ is given by (4). Since all firms face the same problem, they will set the same price. We can therefore eliminate the index i and introduce the index h or f indicating the country of residence of the firm. Prices set by domestic firms selling in market h read as follows:

$$P_{h,t} = \frac{\tilde{\sigma}_{h,t}}{\tilde{\sigma}_{h,t} - 1} \frac{W_t}{A_t}, \tag{9}$$

while prices of foreign firms selling in market h are

$$P_{f,t} = \frac{\tilde{\sigma}_{f,t}}{\tilde{\sigma}_{f,t} - 1} \frac{S_t W_t^*}{A_t^*}, \tag{10}$$

in which S_t denotes the nominal exchange rate (the price of foreign currency in terms of domestic currency), W_t^* denotes nominal wages determined in a foreign labor market (denominated in foreign currency), and A_t^* is the common productivity shifter for firms based in country f. Prices in (9) and (10) have to be solved jointly since the market shares of domestic firms ξ_h, as shown in equation (6), and that of foreign firms, ξ_f, depend themselves on prices.

To analyze more deeply the implications of conditions (9) and (10), it is convenient to take a log-linear approximation together with that of the market shares to obtain

$$\hat{P}_{h,t} = \kappa s_f (\hat{P}_{f,t} - \hat{P}_{h,t}) + \hat{W}_t - \hat{A}_t, \tag{11}$$

$$\hat{P}_{f,t} = \kappa s_h (\hat{P}_{h,t} - \hat{P}_{f,t}) + \hat{W}_t^* + \hat{S}_t - \hat{A}_t^*, \tag{12}$$

where the parameter κ is defined by

$$\kappa \equiv \frac{\sigma - 1}{\bar{\sigma} - 1} \frac{\sigma - \theta}{\bar{\sigma}} \frac{1}{N},$$

with $\bar{\sigma} \equiv \sigma - (\sigma - \theta)/N$, $s_h = N_h/N$, and $s_f = N_f/N$, and where variables with a hat denote log-deviations with respect to the steady state.

4.1 Exchange Rate Pass-Through

Using the reduced form implied by equations (11) and (12), it is possible to study the conditions under which there is full pass-through of exchange rate movements into foreign prices. Pass-through is defined as the response of the prices set by the foreign firms (selling in the market h) to movements in the exchange rate, i.e., $\partial \hat{P}_{f,t} / \partial \hat{S}_t$. Pass-through is full when the response is unitary.

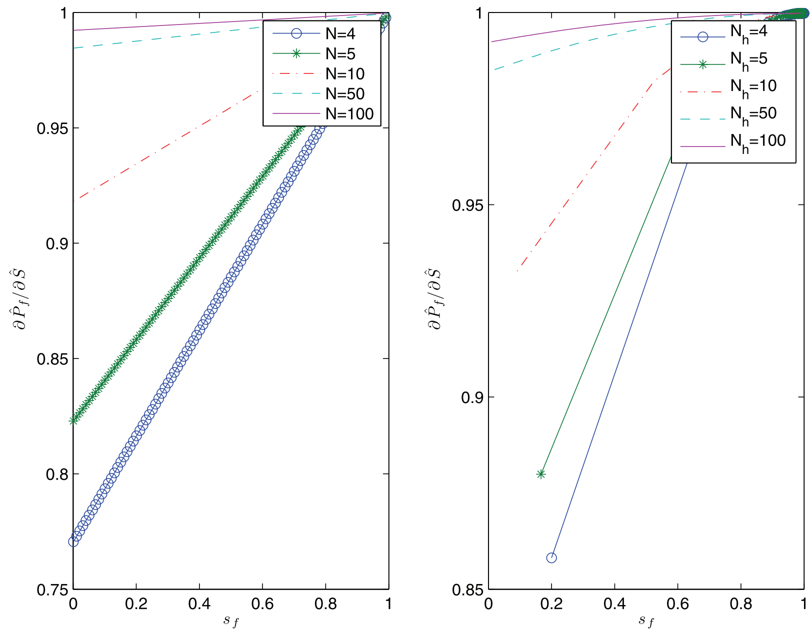
Proposition 1. *With flexible prices, the degree of pass-through is unitary when one of the following conditions is met: (i)* $\sigma = \theta$; *(ii)* $N \to \infty$; *(iii)* $s_h = 0$.

Consider the first condition, $\sigma = \theta$. In this case the elasticity of demand, $\tilde{\sigma}_i$, is constant and independent of the market shares. Firms cannot affect sectoral aggregate prices and therefore a constant elasticity of demand implies full pass-through. The power of firms to affect sectoral aggregate prices is also nil under the second condition, $N \to \infty$. In this case, the market share of each firm becomes negligible like in a monopolistically competitive market. Finally, in the third case ($s_h = 0$), foreign firms dominate completely the domestic market and therefore they can pass-through any exchange rate movement into prices without losing market share.

To summarize, pass-through in the flexible-price equilibrium is high when foreign firms have larger market shares or are very small. In the intermediate cases, the pass-through is less than unitary because firms internalize the effects of their pricing choices on the market shares. Indeed firms foresee that too-large price increases lead to significant losses in market share and thus to reductions in the markup. Therefore, they do not increase prices much when the exchange rate depreciates.

Figure 1 quantifies the exchange rate pass-through as a function of the share of foreign products in the market, which is our measure of the dimension of globalization in the model. Calibration of baseline parameters is as follows: $\sigma = 6, \theta = 1.5$. We interpret the rise in the number of foreign products in the domestic market as an increase in globalization. Given a permanent shock to the exchange rate, the two panels in figure 1 show the degree of pass-through as a function of the share of foreign products in the domestic market. The left panel shows how the degree of pass-through varies when the fraction of foreign products in the market changes on the x-axis and for different values of N. Along each line we keep the total number of products in the market constant. The right panel instead shows the degree of pass-through against the share of foreign products and for different values of N_h. In this case, along each line we keep N_h at a determined value and vary the number of foreign products, and therefore the total number of products. Both pictures show that the pass-through is increasing in the share of foreign products in the

Figure 1. Long-Run Pass-Through ($\partial \hat{P}_{f,t}/\partial \hat{S}_t$) as a Function of the Share of Foreign Products in the Domestic Market, s_f



Notes: In the left panel, N is fixed (at different levels) and s_f is varied from 0 to 1. In the right panel, N_h is fixed (at different levels) and N_f varies from 0 to infinity to imply variation in s_f.

market. Consistent with the theoretical results, the pass-through is 1 when foreign firms dominate the market. Globalization, interpreted as an increase in the fraction of foreign products in the domestic market, leads to higher long-run pass-through and makes foreign prices more responsive to foreign marginal costs and the exchange rate. Moreover, the pass-through is larger in sectors characterized by a low degree of concentration, which in our model can be proxied by the inverse of the total number of firms in the market, i.e., $1/N$. For large values of N, the degree of concentration in the sector is low and the pass-through is very close to 1.

4.2 Response of Domestic Prices to Domestic Conditions

In recent years a large part of the debate on the costs and benefits of the globalization process has pointed toward the possibility that domestic prices could be disconnected from domestic conditions and more influenced by external factors. To the extent that domestic prices are largely driven by foreign marginal costs, the interventions of policymakers to constrain inflation by restraining domestic demand might become less effective. To study the link between domestic prices and marginal costs, we take the difference between equations (11) and (12) and solve for the equilibrium prices:

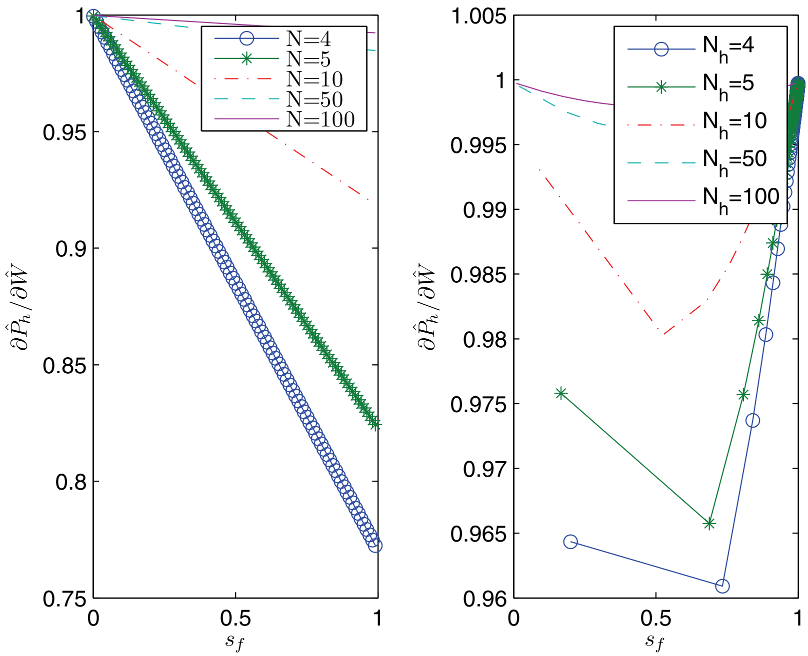
$$\hat{P}_{h,t} = \frac{\kappa s_f}{1+\kappa}(\hat{W}_t^* + \hat{S}_t - \hat{A}_t^*) + \frac{1+\kappa(1-s_f)}{1+\kappa}(\hat{W}_t - \hat{A}_t), \qquad (13)$$

$$\hat{P}_{f,t} = \frac{\kappa s_h}{1+\kappa}(\hat{W}_t - \hat{A}_t) + \frac{1+\kappa(1-s_h)}{1+\kappa}(\hat{W}_t^* + \hat{S}_t - \hat{A}_t^*). \qquad (14)$$

Equation (13) shows that prices of domestic firms selling in market h are a weighted average of domestic and foreign marginal costs. A standard model with monopolistic competition would instead imply prices to be just influenced by domestic marginal costs. Similarly, prices of foreign products sold in the market h are a weighted average of domestic and foreign marginal costs. The pricing competition between domestic and foreign firms creates a link through which movements in marginal costs have spillover effects across firms competing in the same sector. The degree of marginal-cost spillover is affected by the share of foreign firms operating in the market. An increase in the share of foreign products, s_f, tends to foster the link between domestic prices and foreign marginal costs. Conversely, globalization in terms of higher penetration of foreign firms in the domestic market tends to weaken the link between domestic prices and domestic marginal costs. Our model would then be consistent with the "global slack" hypothesis according to which the dynamic of domestic prices is more influenced by the foreign slack as a consequence of globalization.

Figure 2 plots the response of prices to a shock to domestic wages for the firms based in country h and selling products in country h. Once again, two different cases are examined. The left panel of figure 2 shows how the response of domestic prices to domestic wages varies with respect to changes in the fraction of foreign products (on the

Figure 2. Long-Run Response of Domestic Prices to Domestic Wages ($\partial\hat{P}_{h,t}/\partial\hat{W}_t$) as a Function of the Share of Foreign Products in the Domestic Market, s_f



Notes: In the left panel, N is fixed (at different levels) and s_f is varied from 0 to 1. In the right panel, N_h is fixed (at different levels) and N_f varies from 0 to infinity to imply variation in s_f.

x-axis) and for different (given) values of N. The right panel of figure 2 shows how the response of domestic prices to domestic wages varies with respect to changes in the share of foreign products, this time for different (given) values of N_h. In the first panel, the response of prices to wages is smaller as the share of foreign firms increases. The reduction is larger the higher is the degree of concentration in the sector captured by $1/N$. On the contrary, the right panel shows a bell-shaped response. When there are only domestic firms in the domestic market, h, the response of domestic prices to a wage shock is unitary. This is also the case when the share of foreign firms is large and, most important, when the degree of concentration in the market is very small, since N goes to infinity. For intermediate values, the response is less than unitary. Overall, two main conclusions arise. Globalization reduces the response of domestic prices to movements in domestic marginal costs when foreign firms enter the market to replace domestic firms without changing the overall degree of concentration in the sector. When the entrance of foreign firms raises the total number of firms in the domestic market, hence increasing the degree of competition, things are more complex. When a small number of foreign firms enters the domestic market, domestic prices become less sensitive to domestic conditions. However, as the number of foreign firms becomes large, domestic prices become again highly connected to domestic marginal costs, since domestic firms are small.

5. Sticky Prices

In this section, we study the implications of adding price rigidities through a cost of adjusting prices as in the model of Rotemberg (1982).[6] There are three main implications of the new environment. It is now possible to study the interaction between sticky prices and pricing competition in characterizing the degree of exchange rate pass-through and the sensitivity of prices to movements in the marginal costs. Moreover, the presence of price rigidities allows one to disentangle short-run versus long-run effects of marginal-cost shocks into prices, in line with the empirical evidence. Finally, it is possible to derive a New Keynesian Phillips curve linking inflation, marginal costs, and the additional elements implied by our model.

In our model a generic firm i, based in country h, producing in a generic sector k of market h maximizes the present discounted value of profits:

$$E_t \sum_{\tau=t}^{\infty} R_{t,\tau} \left[P_{i,\tau} Y_{i,\tau} - \frac{W_\tau}{A_\tau} Y_{i,\tau} - \frac{\chi}{2} \left(\frac{P_{i,\tau}}{P_{i,\tau-1}} - 1 \right)^2 P_{i,\tau} Y_{i,\tau} \right], \quad (15)$$

[6] Alternative models of price-setting decisions—as, for example, Calvo (1983)—could have been considered.

where χ, with $\chi \geq 0$, is a parameter measuring the cost of adjusting prices, while $R_{t,\tau}$ is a nominal stochastic discount factor through which units of wealth are appropriately evaluated across time and states of nature. The optimality condition requires prices to be set as a time-varying markup over nominal marginal costs:

$$P_{i,t} = \tilde{\mu}_{i,t} \frac{W_t}{A_t}. \tag{16}$$

However, in this case, the markup is a more complicated expression and, in particular, is a function of past and future expected variations in prices as shown by

$$\tilde{\mu}_{i,t} = \frac{\tilde{\sigma}_{i,t}}{(\tilde{\sigma}_{i,t} - 1)\left[1 - \frac{\chi}{2}(\pi_{i,t} - 1)^2\right] + \chi \pi_{i,t} (\pi_{i,t} - 1) - \Gamma_t}, \tag{17}$$

with

$$\Gamma_t \equiv \chi E_t \left\{ R_{t,t+1} \pi_{i,t+1} (\pi_{i,t+1} - 1) \frac{Y_{i,t+1}}{Y_{i,t}} \right\}, \tag{18}$$

and $\pi_{i,t} \equiv P_{i,t}/P_{i,t-1} - 1$.[7]

To get further insights, we take a first-order approximation of (16), which delivers the following New Keynesian Phillips curve:

$$\pi_{h,t} = \left[k \cdot mc_t + \frac{\sigma - \theta}{\chi \bar{\sigma}} \frac{1}{N} \cdot \hat{\xi}_{h,t} \right] + \beta E_t \pi_{h,t+1}, \tag{19}$$

where we have defined the domestic real marginal costs as $mc_t \equiv (\hat{W}_t - \hat{P}_{h,t} - \hat{A}_t)$ and the slope k is given by $k \equiv (\bar{\sigma} - 1)/\chi$.

Compared with the traditional New Keynesian Phillips curve, the one derived above is characterized by an additional element represented by the second addendum in the square bracket. This element captures the novel aspect of strategic pricing featured by our model. When firms interact strategically, the aggregate supply equation shifts with the movements in the markup which are driven

[7]We focus on a symmetric equilibrium in which all firms within a sector set the same price. However, it might be possible that there are multiple equilibria given the non-linearity of the right side of (17). In what follows, we abstract from them.

by variation in firms' market share. When N approaches infinity, namely under a monopolistically competitive market, or when $\sigma = \theta$, the equation nests the traditional New Keynesian Phillips curve.

Two elements differentiate the Phillips curve of this model from the traditional one and describe the influence of firms' globalization on the aggregate supply equation. The first element is the slope of the curve, i.e., the short-run relationship between inflation and domestic real marginal costs, which now depends upon the number of products present in the market. Indeed $\bar{\sigma}$ is an increasing function of N. The higher the number of products, the higher is the steady-state elasticity of substitution and the higher is the response of inflation to movements in the real marginal costs. Hence, from this point of view higher competition steepens the Phillips curve and renders price more sensitive to domestic shocks. In a closed-economy model with Kimball's (1995) preferences and monopolistic competition, Sbordone (2007) also finds that the slope of the curve is influenced by the number of varieties in the market; however, in her case such relation changes direction depending on parameters' calibration.[8]

The second element that characterizes equation (19) with respect to the traditional New Keynesian Phillips curve stems from the influence exerted by the fluctuations in market share over the markup of domestic firms. This influence is captured by the second term in the square bracket of equation (19). In the canonical open-economy model (see Benigno and Benigno 2008), the AS equation is isomorphic to the closed-economy equation:

$$\pi_{h,t} = \tilde{k} \cdot mc_t + \beta E_t \pi_{h,t+1}, \tag{20}$$

for some parameter $\tilde{k}$. In particular, the open-economy channels influencing the inflation dynamics are hidden under the decomposition of the real marginal costs, which is the sum of the output gap and terms of trade. In particular, foreign prices influence the terms of trade and then the real marginal cost. Woodford (2007) has noticed that in this model the "global slack" hypothesis might be

[8]Sbordone (2007) uses a Calvo model which implies a different and opposite relationship than the Rotemberg model between the slope of the AS equation and the parameter $\bar{\sigma}$.

contradicted. Indeed, for realistic calibrations, a decrease in foreign prices, improving the terms of trade, would raise the real marginal costs and put upward pressure on prices instead of the downward pressure commonly thought.

Our model features an additional channel on top of the real marginal costs of equation (20) which results from variations in the market share for the domestic firms, as shown in (19). Since the market share can be approximated by the relative prices,

$$\hat{\xi}_{h,t} = (\sigma - 1)s_f(\hat{P}_{f,t} - \hat{P}_{h,t}),$$

the Phillips curve can be written as follows:

$$\pi_{h,t} = k \cdot \left[mc_t + \kappa s_f(\hat{P}_{f,t} - \hat{P}_{h,t})\right] + \beta E_t \pi_{h,t+1}.$$

This shows the direct influence of the relative prices on domestic inflation. This effect is akin to the channel studied by Guerrieri, Gust, and Lopez-Salido (2010), although in their model it arises assuming kinked demand as in Kimball (1995). On the contrary, in our model, it depends on primitive foundations based on firms' strategic interaction. Those differences allow us to interpret the primitive parameters of our model in light of the pro-competitive effects typical of the globalization process. In particular, the additional relative price channel disappears under two circumstances. The first is when all firms become small in size (N goes to infinity, implying that κ goes to zero); this nests the case of a monopolistically competitive market. The second circumstance is when the share of foreign firms is small (s_f goes to zero), or finally in the particular case in which $\sigma = \theta$, implying also that κ goes to zero. To appreciate the contribution of our more microfounded model, note the difference with Guerrieri, Gust, and Lopez-Salido (2010) in which the additional relative price channel disappears only when there are no foreign products in the domestic market.

Equation (19) can now be used to discuss the impact of globalization on the price behavior of firms, namely on the slope and the shift of the aggregate supply equation. Globalization, as captured by an increase in N_f, raises N and, for given N_h, implies an increase in the slope of the Phillips curve. This channel is not present in Guerrieri, Gust, and Lopez-Salido (2010). Hence, on the one side, globalization makes prices more sensitive to variations in the marginal costs as $\bar{\sigma}$ increases. On the other side, in a globalized market, domestic firms compete for market share with foreign firms, hence the relative market share, as proxied by the relative prices, shifts the AS equation for given domestic marginal costs. For instance, a fall in the foreign prices with respect to the domestic prices reduces the market share of domestic firms and induces a deflationary pressure on domestic prices. Holding constant the size of the market, N, an increase in the share of foreign products reinforces this channel. Hence we conclude that globalization, interpreted as an increase in competition from foreign firms, renders the AS equation more dependent upon foreign conditions, namely foreign prices and foreign marginal costs. Finally, let's consider the case in which N_f rises with N (keeping N_h constant). The effect of N_f on the strength of the relative price channel is less obvious. At low values of N_f, a further rise in the number of foreign firms increases the importance of the relative price channel, whereas in markets characterized by high competition of foreign firms and low concentration, an increase in the number of foreign firms abates the relative price channel. Eventually when N goes to infinity, the relative price channel vanishes.

5.1 Exchange Rate Pass-Through

The degree of exchange rate pass-through depends now on the interaction between price stickiness and strategic pricing among firms. We leave to the working paper version, Benigno and Faia (2010), the detailed solution of the model. Here we briefly summarize the main implications. The degree of pass-through is decreasing when price rigidity of foreign firms increases. Moreover, for a fixed level of rigidity, the higher the concentration in the industry, the lower is the pass-through, but also, when rigidity increases, the concentration in the industry has a smaller impact on the degree of pass-through. In general, globalization might increase the degree of pass-through, for a given degree of nominal rigidity—the more so the lower the degree of rigidity. Concerning domestic prices, their response to movements in domestic marginal costs is smaller the higher the degree of price rigidity, but is relatively smaller in sectors characterized by higher concentration, since competition is stronger. Globalization should therefore reduce the response of prices to domestic conditions—the more so the lower the degree of rigidity. This is always true when we fix the total number of firms in the market. On the contrary, when we fix the number of domestic products in the market, and let the foreign products enter the market freely, we get an ambiguous result as for the flexible-price model. When starting from a small share of foreign products in the market, a further increase in the number of foreign products lowers the response of domestic price to domestic conditions. Instead, when starting from a large share of foreign products, an increase in foreign products reduces the degree of concentration in the industry up to the point that the response of domestic prices to domestic conditions becomes unitary.

6. Empirical Analysis

Our empirical analysis is divided into two parts. In the first part, we explore the consequences of globalization on the degree of exchange rate pass-through by highlighting the role of international competition. In the second part, we stress the importance of globalization for the dynamic of domestic inflation.

6.1 Globalization and Exchange Rate Pass-Through

In our model, globalization raises the degree of exchange rate pass-through. In particular, this depends on the share of foreign products competing in the domestic market and on the degree of concentration in the reference market. Greater competition, due to an increase in the foreign products sold in a particular industry, raises the exchange rate pass-through both in the short and in the long run.

To test this channel we proceed in various steps using data at an aggregate level corresponding to the one-digit harmonized system (HS) classifications. The appendix discusses in detail the sectors analyzed. Data are monthly and the sample goes from 1993 (M12) to 2012 (M2). Sections III, XIX, and XXI in the HS classifications are excluded because data are available on a shorter sample or missing. We shall note that our data sample is rather short, an unavoidable constraint for us. This plays against the statistical significance of the results, at least for some sectors. But precisely for this reason, we read the results reported below as reasonably good given the constraints.

To study exchange rate pass-through, we run seemingly unrelated regressions on a model with the following benchmark specification:

$$\Delta p_{k,t} = c_k + \sum_{j=1}^{n} \gamma_{k,j} \Delta p_{k,t-j} + \sum_{j=0}^{m} \beta_{k,j} \Delta s_{t-j} + \varepsilon_{k,t}, \tag{21}$$

where $\Delta p_{k,t}$ represents the change in log nominal import price of a generic sector k at time t and Δs_t represents the change in the U.S. effective nominal exchange rate, c_k is a generic constant, $\gamma_{k,i}$ measures the dependence of price changes to its lag values at time $t-i$, and $\beta_{k,j}$ is the sector-specific coefficient measuring the response of prices to nominal exchange rate movements at lag $t-j$.[9] With Stein's unbiased risk estimator (the SURE estimator), we are allowing the unobserved shocks $\varepsilon_{k,t}$ to co-vary across the different sectors. We define the long-run pass-through as $\sum_{j=0}^{m} \beta_{k,j}/(1 - \sum_{i=1}^{n} \gamma_{k,i})$.

We also consider the following alternative specifications for computing the price increments: yearly differences, $\Delta_y p_t$, and two-year differences, $\Delta_{2y} p_t$. We regress them on the corresponding time differences of the nominal exchange rate as follows:

$$\Delta_y p_{k,t} = c_k + \beta_k \Delta_y s_t + \varepsilon_{k,t}, \tag{22}$$

$$\Delta_{2y} p_{k,t} = c_k + \beta_k \Delta_{2y} s_t + \varepsilon_{k,t}. \tag{23}$$

Results on the long-run degree of pass-through are shown in table 1, where model A corresponds to (21), model B to (22), and model C to (23). The table shows that for all the sectors, except for sector I, the pass-through coefficients are positive and significantly different from zero across all the specifications. Large values are found in sectors V, XIV, and XV, which correspond to mineral products, stone and precious metals, and base metals, respectively.

To study the effect of globalization on the degree of pass-through, we investigate whether it has changed in recent years and, in particular, if there has been a noticeable increase in the last decade. We run the regression on model (21) by splitting the sample into two parts. We do this according to two different criteria. First, we use the share of import from China in the United States as a proxy of the

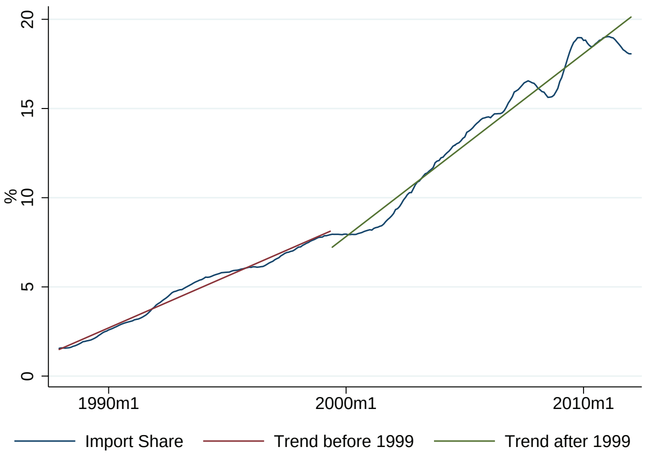
[9] Lags are chosen according to the Akaike information; therefore n is set to 2 and m to 2.

Table 1. Estimated Pass-Through Coefficients for Sectors in the HS Classifications

Sector	Model A	Model B	Model C
I	−0.17	−0.04	0.17**
	(0.16)	(0.07)	(0.06)
II	0.56**	0.78***	0.96***
	(0.23)	(0.11)	(0.09)
IV	0.27***	0.34***	0.44***
	(0.05)	(0.03)	(0.03)
V	1.77***	3.2***	2.56***
	(0.60)	(0.27)	(0.23)
VI	0.39***	0.45***	0.56***
	(0.08)	(0.04)	(0.04)
VII	0.34***	0.52***	0.67***
	(0.07)	(0.04)	(0.03)
VIII	0.08***	0.13***	0.16***
	(0.02)	(0.02)	(0.02)
IX	0.25	0.45***	0.47***
	(0.24)	(0.11)	(0.08)
X	0.34	0.34***	0.49***
	(0.21)	(0.1)	(0.07)
XI	0.09**	0.12***	0.11***
	(0.04)	(0.02)	(0.02)
XII	0.01	0.03**	0.06***
	(0.02)	(0.01)	(0.01)
XIII	0.04	0.07***	0.17***
	(0.03)	(0.02)	(0.03)
XIV	0.63***	0.83***	0.84***
	(0.16)	(0.1)	(0.09)
XV	1.18***	1.11***	1.36***
	(0.21)	(0.1)	(0.07)
XVI	0.16***	0.21***	0.28***
	(0.03)	(0.02)	(0.02)
XVII	0.08***	0.08***	0.07***
	(0.02)	0.01	(0.009)
XVIII	0.16***	0.17***	0.022***
	(0.03)	(0.02)	(0.01)
XX	0.08***	0.09***	0.16***
	(0.02)	(0.02)	(0.02)

Notes: Full sample 1993:M12–2012:M2. Model A corresponds to equation (21), model B corresponds to equation (22), and model C corresponds to equation (23). Standard errors are in parentheses. ***, **, and * denote significance at the 1 percent, 5 percent, and 10 percent level, respectively.

Figure 3. Import Share from China in the United States, Break Point at 1999:M6.



Note: Trends before and after are shown.

trend in globalization. As shown in figure 3, there is a change in the trend identifiable in June 1999 through an Andrews (1993) test. We split the sample around this month and estimate the pass-through before and after this break. Results are shown in table 2.[10]

Evidence shows an increase in pass-through for ten out of eighteen sectors considered: sectors I (Live Animals and Animal Products), IV (Prepared Foods), V (Mineral Products), VI (Products of Chemical Industries), VII (Plastics and Related Articles), IX (Wood, etc.), XI (Textiles), XIV (Pearl, Stones, etc.), XV (Precious Metals), and XX (Miscellaneous Manufactured Articles). For the remaining sectors the pass-through decreased: specifically, this holds for sectors II (Vegetable Products), VIII (Raw Hides, etc.), X (Wood Pulp, etc.), XII (Headgear, Umbrellas, etc.), XIII (Stone, Cement), XVI (Machinery, Electrical Equipment, etc.), XVII (Vehicles, etc.), and XVIII (Optical, Photo, etc.).[11]

[10]In the table, the "stars" close to the roman numerals of the HS sectors refer to the significance of the break point through a Chow test.

[11]The table also shows when the difference between the coefficients of the two samples is statistically significant.

Table 2. Estimated Pass-Through Coefficients Using Model (21) for Sectors in the HS Classifications

Sector	Before 1996:M6	After 1999:M6
I	−0.28*	−0.11
	(0.16)	(0.22)
II	0.84	0.5**
	(0.63)	(0.24)
IV	0.07	0.32***
	(0.09)	(0.07)
V	−0.04	2.31***
	(1.2)	(0.73)
VI	0.22**	0.41***
	(0.1)	(0.1)
VII	0.03	0.38***
	(0.21)	(0.07)
VIII***	0.2***	0.05
	(0.06)	(0.03)
IX	−0.16	0.4
	(0.3)	(0.31)
X	0.88	0.15
	(1.17)	(0.12)
XI	0.03	0.12**
	(0.05)	(0.05)
XII*	0.05*	−0.01
	(0.02)	(0.03)
XIII	0.15**	0.00
	(0.07)	(0.04)
XIV	0.17	0.73***
	(0.12)	(0.22)
XV***	0.13	1.45***
	(0.33)	(0.26)
XVI**	0.29***	0.1***
	(0.07)	(0.02)
XVII	0.13***	0.07***
	0.04	(0.02)
XVIII***	0.33***	0.1***
	(0.07)	(0.03)
XX**	0.07*	0.09**
	(0.04)	(0.04)

Notes: The sample is split into two parts: 1993:M12–1999:M6 and 1999:M7–2012:M2. Standard errors are in parentheses. ***, **, and * denote significance at the 1 percent, 5 percent, and 10 percent level, respectively. The "stars" next to the sector's roman numeral refer to a Chow test on the significance of the break date.

Table 3. Andrews Test for the Estimates (with Eight-Year Rolling Window) of Long-Run Pass-Through Coefficient Using Model (21)

Sector	Test	Break
I	1.17	2001:M5
II	0.71	2005:M11
IV	10.23**	2006:M1
V	8.73**	2006:M6
VI	2.79	2003:M8
VII	2.8	2000:M12
VIII	5.44	1998:M11
IX	3.8	2001:M11
X	2	2003:M5
XI	3.58	2003:M7
XII	3.9	1998:M11
XIII	12.9***	2007:M6
XIV	5	1999:M4
XV	12.98***	2003:M11
XVI	6.59*	2002:M5
XVII	1.56	1999:M8
XVIII	12***	1998:M11
XX	0.2	1998:M12

Notes: The table reports the sector, the value of the test, and the break point. ***, **, and * denote significance at the 1 percent, 5 percent, and 10 percent level, respectively.

To gauge a second criterion for splitting the sample, we estimate (21) on a rolling-window basis of eight years and test for a break in the rolling estimates of the pass-through, separately for each sector, using again the Andrews (1993) test. Results of the tests are presented in table 3. There is a significant break only for a few sectors, IV, V, XIII, XV, and XVIII with different break dates. For all sectors, we divide the sample according to the break points identified by the Andrews test, even if not significant, and report estimates before and after the break. Results are presented in table 4: although the split is different, the results are in line with our previous analysis.

To deepen the assessment of the role of foreign firms' penetration on pass-through, we regress the pass-through coefficients

Table 4. Estimated Pass-Through Coefficients Using Model (21) for Sectors in the HS Classifications, Using Andrews Test to Split Sample

Sector	First Sample	Second Sample
I	−0.4**	−0.06
	(0.17)	(0.25)
II	0.73**	0.34
	(0.36)	(0.28)
IV	0.07	0.41***
	(0.07)	(0.07)
V	0.29	3.63***
	(0.73)	(0.86)
VI	0.2**	0.47***
	(0.08)	(0.13)
VII	0.06	0.39***
	(0.17)	(0.08)
VIII	0.23***	0.05
	(0.06)	(0.03)
IX	−0.44	0.52*
	(0.4)	(0.3)
X	1.09	0.07
	(0.7)	(0.09)
XI	0.01	0.2**
	(0.03)	(0.08)
XII	0.08**	−0.01
	(0.03)	(0.03)
XIII	0.15***	−0.07*
	(0.04)	(0.04)
XIV	0.17	0.74***
	(0.13)	(0.22)
XV	0.24	1.6***
	(0.19)	(0.33)
XVI	0.27***	0.09***
	(0.06)	(0.02)
XVII	0.13***	0.07***
	(0.04)	(0.02)
XVIII	0.38***	0.1***
	(0.07)	(0.02)
XX	0.06	0.09**
	(0.04)	(0.04)

Notes: The sample is split into two parts according to the break points identified using the Andrews test as shown in table 3. Standard errors are in parentheses. ***, **, and * denote significance at the 1 percent, 5 percent, and 10 percent level, respectively.

(from model A), estimated via (eight years) rolling-window samples, on a foreign firm penetration index which is proxied by the share of imports from China over total sectoral imports. The index was taken from the U.S. Census Bureau and was available at yearly frequency.[12] We focus on analyzing the relationship between pass-through and the above-mentioned indexes for the sectors in which pass-through went up after the breakup date (sectors I, IV, V, VI, VII, IX, XI, XIV, XV, and XX). Table 5 shows the results. For all sectors (except sectors V and XX) we find a positive and significant (up to 95 percent confidence interval) relation between the pass-through and the penetration index. Note, in particular, that sector V behaves as an outlier given that the estimated coefficient appears strangely high and it is not significant at 95 percent.

To further assess the robustness of the results on the penetration index, we regress the estimated pass-through coefficients on both the China penetration index and a concentration/competition index, which we proxy with the Herfindhal index (also taken from the U.S. Census Bureau).[13] Results, not reported, show that while the coefficient on the China index remains mostly significant and positive, turning out positive also for sector V, the coefficients of the Herfindhal index are actually insignificant in all cases (except positive coefficients for sectors V and IX). There are two obstacles, both unavoidable, for which this regression might not work properly. The first relates to the classification of the sectors considered. Indeed the Herfindhal index follows a different classification, namely the North American Industry Classification System (NAICS). For this reason we had to match the sectors of NAICS classification with the sectors in the HS classification: the matching, although accurate, might be far from perfect, and at the end we had to disregard sectors I and XIV.[14] Furthermore, the Herfindhal index is not available on a regular basis throughout our sample. Second, the two indexes might be correlated with each other, as they both refer to market shares.

[12] In order to harmonize the data samples in terms of their frequencies, we have taken the end-of-year observation of the monthly pass-through estimated coefficients. See the appendix for details.

[13] We also considered two alternative indexes given by the share of value added of the fourth and eighth largest firms.

[14] See the appendix for a description of the matching.

Table 5. Linear Regression of Estimated Pass-Through Coefficients Using Model (21)

Var.	I	IV	V	VI	VII	IX	XI	XIV	XV	XX
China	0.36***	0.26***	−1.35	0.43***	0.42***	0.44***	0.15***	0.26***	1.28***	−0.03
	(0.06)	(0.03)	(0.92)	(0.10)	(0.10)	(0.13)	(0.04)	(0.08)	(0.18)	(0.05)
Const.	0.78***	1.16***	−5.50	1.78***	1.15***	1.29***	0.32***	1.34***	3.82***	0.07*
	(0.20)	(0.11)	(4.44)	(0.35)	(0.20)	(0.33)	(0.08)	(0.28)	(0.43)	(0.03)

Notes: The table shows linear regression of estimated pass-through coefficients using model (21) against a penetration index of foreign firms represented by the share of imports from China over total imports (index_China). Sectors selected are the ones for which pass-through went up in the latest samples. Newey-West standard errors are in parentheses (lag = 1). ***, **, and * denote significance at the 1 percent, 5 percent, and 10 percent level, respectively.

To further evaluate the robustness of our results, we modify the benchmark regression by adding two additional variables as follows:

$$\Delta p_{k,t} = c_k + \sum_{j=1}^{n} \gamma_{k,j} \Delta p_{k,t-j} + \sum_{j=0}^{m} \beta_{k,j} \Delta s_{k,t-j} + \sum_{j=0}^{l} \varsigma_{k,j} \Delta p^c_{t-j} + \sum_{j=0}^{p} \delta_{k,j} i_{t-j} + \varepsilon_{k,t}, \quad (24)$$

where p^c_t is a price index of all commodities and i_t is the U.S. short-term interest rate. Variations in the commodity price index can capture important determinants of price changes besides exchange rate movements. Marazzi and Sheets (2007) have emphasized that the inclusion of this variable can be critical to determine a decline in pass-through during the period 1996–2004, while its omission can imply higher and quite volatile pass-through coefficients. The short-term interest rate, instead, captures aggregate determinants of prices which depend on the transmission mechanism of monetary policy directed toward the control of aggregate inflation. If the exchange rate depreciates or if the commodity price increases, monetary policy can react by raising nominal interest rate to curb the inflationary pressure and therefore to contain the variations of sectoral prices. Without the inclusion of an index of monetary policy stance, our pass-through coefficients could be biased toward low or even negative values.

We repeat our previous analysis by first estimating equation (24) and setting $\delta_{k,j} = 0$ for all k and j. Then we include also the nominal interest rate. Here, to save space, we only report the new results in a format equivalent to that of table 2. In particular, table 6 is the equivalent of table 2 when the model estimated is the one in (24) and in which $\delta_{k,j} = 0$ for all k and j. Table 7 considers the general unrestricted case.[15]

Looking at the specification which includes only the commodity price index, our results on the increase of pass-through are weakened but not overturned. The number of sectors in which pass-through increases is lower, seven instead of ten. However, the increase in

[15] In the regression of table 6, $m = n = l = 2$, while in that of table 7, $m = 1$ and $l = p = n = 2$.

Table 6. Estimated Pass-Through Coefficients Using Model (24), Assuming $\delta_{kj} = 0$ for All k and j for Sectors in the HS Classifications

Sector	Before 1996:M6	After 1999:M6
I	−0.27	−0.48*
	(0.17)	(0.28)
II*	0.34	0.66**
	(0.58)	(0.29)
IV	0.02	0.23***
	(0.09)	(0.09)
V	0.01	0.16
	(0.85)	(0.46)
VI	0.14	0.12
	(0.09)	(0.11)
VII	−0.06	0.17**
	(0.21)	(0.08)
VIII*	0.19***	0.05
	(0.07)	(0.04)
IX	−0.18	−0.15
	(0.31)	(0.36)
X	0.72	−0.005
	(1.17)	(0.15)
XI	0.006	0.10
	(0.05)	(0.07)
XII	0.05	−0.009
	(0.03)	(0.05)
XIII	0.11	0.03
	(0.07)	(0.05)
XIV	0.25**	0.24
	(0.12)	(0.25)
XV	0.005	0.58**
	(0.30)	(0.25)
XVI	0.29***	0.11***
	(0.08)	(0.03)
XVII	0.14***	0.05*
	(0.04)	(0.03)
XVIII*	0.33***	0.12***
	(0.07)	(0.04)
XX	0.07*	0.10*
	(0.04)	(0.05)

Notes: The sample is split into two parts: 1993:M12–1999:M6 and 1999:M7–2012:M2. Standard errors are in parentheses. ***, **, and * denote significance at the 1 percent, 5 percent, and 10 percent level, respectively. The "stars" next to the sector's Roman numeral refer to a Chow test on the significance of the break date.

Table 7. Estimated Pass-Through Coefficients Using Model (24) for Sectors in the HS Classifications

Sector	Before 1996:M6	After 1999:M6
I	0.09	−0.45**
	(0.12)	(0.22)
II*	−0.01	0.55**
	(0.44)	(0.23)
IV	0.05	0.17**
	(0.08)	(0.07)
V	0.35	0.12
	(0.79)	(0.35)
VI	0.17**	0.11
	(0.07)	(0.08)
VII	0.05	0.15**
	(0.16)	(0.07)
VIII**	0.15***	0.04
	(0.05)	(0.03)
IX	−0.00002	−0.40
	(0.26)	(0.27)
X*	1.12	−0.06
	(0.88)	(0.11)
XI	0.03	0.08
	(0.04)	(0.05)
XII	0.03	0.03
	(0.03)	(0.03)
XIII	0.11*	0.06
	(0.06)	(0.04)
XIV	0.35***	0.44**
	(0.10)	(0.19)
XV	0.08	0.84***
	(0.23)	(0.21)
XVI	0.33***	0.12***
	(0.06)	(0.03)
XVII***	0.15***	0.08***
	(0.03)	(0.02)
XVIII*	0.34***	0.12***
	(0.06)	(0.03)
XX	0.06*	0.06
	(0.03)	(0.04)

Notes: The sample is split into two parts: 1993:M12–1999:M6 and 1999:M7–2012:M2. Standard errors are in parentheses. ***, **, and * denote significance at the 1 percent, 5 percent, and 10 percent level, respectively. The “stars” next to the sector’s Roman numeral refer to a Chow test on the significance of the break date.

pass-through is now strong also for sector II (Vegetable Products). Results are confirmed for sectors IV, V, VII, XI, XV, and XX. Looking at the specification in which we also control for the monetary policy stance, we lose supportive evidence for sectors V and XIV, but gain it for sector XIV (Pearl, Stones, etc.). On the contrary, it should be noted that for the sectors XVI (Machinery, Electrical Equipment, etc.), XVII (Vehicles, etc.), and XVIII (Optical, Photo, etc.), the evidence of a declining pass-through is robust across all specifications.

Overall our findings confirm some of the previous results in the literature on partial exchange rate pass-through, but also add some novel dimensions.[16] We find mixed evidence that globalization has increased the degree of pass-through. For the sectors supporting our results, an index of market penetration of foreign firms has an explanatory power in line with the theoretical implications of the model.

6.2 Globalization and the AS Equation

The second empirical implication of our model refers to the AS equation, which is now augmented by the relative price channel:

$$\pi_{h,t} = k \cdot \left[mc_t + \kappa s_f (\hat{P}_{f,t} - \hat{P}_{h,t}) \right] + \beta E_t \pi_{h,t+1}. \qquad (25)$$

Two main features characterize the new AS equation. First, the global slack component, represented by the term $\kappa s_f(\hat{P}_{f,t} - \hat{P}_{h,t})$, plays a significant role. Second, the slope of the Phillips curve, represented by the parameter k, depends on the goods market competition and therefore can change with the globalization process. We estimate equation (25) to see to what extent our channels are confirmed by the data. There are several estimation methods to test the AS equation (25). We follow the one in Sbordone (2002). We write the AS equation as follows:

$$\hat{P}_{h,t} - \hat{P}_{h,t-1} = k(ulc_t - \hat{P}_{h,t}) + k\kappa s_f \cdot pr_t + \beta E_t(\hat{P}_{h,t+1} - \hat{P}_{h,t}),$$

[16] Earlier papers find evidence of partial pass-through, hence rejecting both producer-currency pricing and local-currency pricing as characterizations of aggregate behavior (see Campa and Goldberg 2005 for an empirical analysis on OECD countries and Bugamelli and Tedeschi 2008 for evidence on euro-area countries).

where we define $mc_t \equiv (ulc_t - \hat{P}_{h,t})$, ulc_t as unit labor costs, and the relative prices pr_t as $pr_t \equiv (\hat{P}_{f,t} - \hat{P}_{h,t})$. The above equation is solved forward with respect to $\hat{P}_{h,t}$ to obtain

$$\hat{P}_{h,t} = \phi_1 \hat{P}_{h,t-1} + (1-\phi_1)(1-\phi_2^{-1})E_t \times \left\{ \sum_{T=t}^{\infty} \phi_2^{-(T-t)} [ulc_T + \kappa s_f \cdot pr_T] \right\}, \qquad (26)$$

where ϕ_1 is given by

$$\phi_1 = \frac{1+\beta^{-1}+k\beta^{-1} - \sqrt{(1+\beta^{-1}+k\beta^{-1})^2 - 4\beta^{-1}}}{2},$$

and $\phi_2 = (\phi_1\beta)^{-1}$. The next step is to rearrange equation (26) as follows:

$$(\hat{P}_{h,t} - ulc_t) = \phi_1(\hat{P}_{h,t-1} - ulc_{t-1}) - \Delta ulc_t + (1-\phi_1)E_t \times \left\{ \sum_{T=t}^{\infty} (\beta\phi_1)^{(T-t)} [\Delta ulc_T + \omega \cdot pr_T] \right\}, \qquad (27)$$

where $\omega \equiv \kappa s_f$.

Equation (27) allows to us test the relation between the log-difference of domestic prices on one side and unit labor costs, their lags, their future expectations, and relative prices on the other. This relation depends on the parameters ϕ_1 and ω, which are in turn related to the deep parameters of the model. In particular, the parameter ϕ_1 depends upon k, the slope of the Phillips curve, and β, the discount factor, while the parameter ω depends upon κ and s_f, which are proxies of the market share. Since it is not possible to identify separately the parameters κ and s_f, as well as the parameters β and k, we focus on identifying the slope of the AS equation, k, and the parameter, ω. The latter is a crucial parameter, as it captures the importance of the relative price channel as emphasized by our model. Moreover, assuming that $\beta = 0.99$, as is standard in a quarterly model, we can identify k.

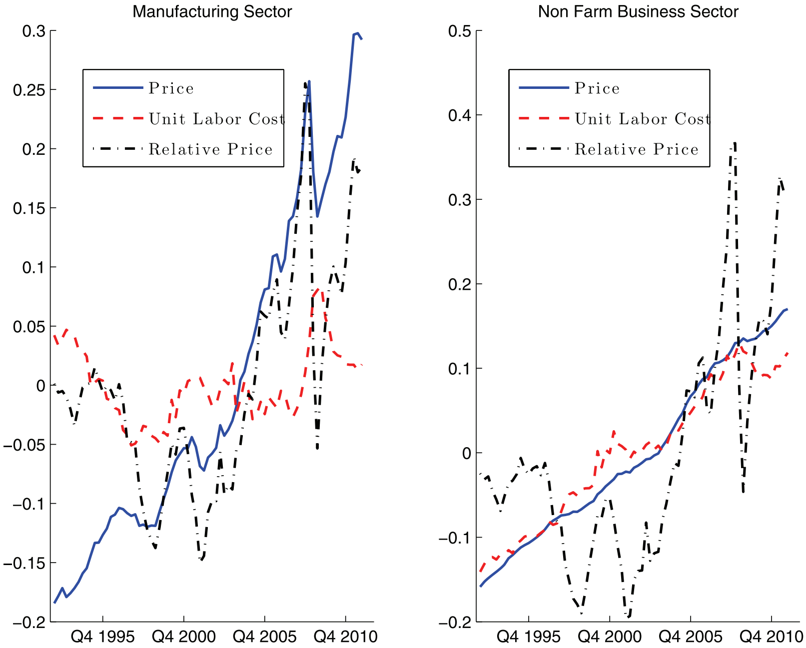
To evaluate the right side of (27), we need to compute expectations of future changes in the unit labor costs and future relative prices. To this end, we use a vector autoregression (VAR) model with four lags involving the following vector of variables: $X_t = [(\hat{P}_{h,t} - ulc_t)\ \Delta ulc_t\ pr_t]$. Therefore, for a combination of parameters k and ω, we can get the model-implied log-difference between prices and unit labor costs. To estimate k and ω, we search for the values that minimize the criterion $\sum_{t=1}^{T} \varepsilon_t^2/T$, where ε_t measures the distance between the model-implied $(\hat{P}_{h,t} - ulc_t)$ and the data. In particular, we run a grid-search analysis for the parameters k and ω under the non-negative constraint.

We estimate equation (25) on two different data sets and using different time samples. On the one side, we use data on prices and unit labor costs for the non-farm business sector, which has been traditionally used to test closed-economy New Keynesian AS curves. On the other side, we use data on prices and unit labor cost for the manufacturing sector. Data for the latter sector have never been used before in testing the New Keynesian Phillips curve, although they are particularly relevant for our experiment, as this sector has been heavily exposed to the trade and firms' globalization process in the last decade.

Figure 4 plots the log of prices and unit labor costs for the two sectors analyzed together with the appropriate relative price, defined as the log in the price of import with respect to the domestic price. The import price index is constructed by aggregating sectoral import price indexes belonging to the HS classifications, as discussed in the appendix. Such aggregation is possible only for the period 1993–2012. To appreciate the difference between the two sectors in terms of their exposure to globalization, figure 4 is illustrative. In the non-farm business sector there is a strong relationship between prices and unit labor costs. This is not the case in the manufacturing sector, where unit labor costs have decreased in the past decades but prices have instead increased. However, in this sector, prices are positively correlated with the relative price, and therefore with the import prices, suggesting that international competition might be an important aspect influencing the dynamic of domestic prices.

When computing Phillips-curve estimations, we perform the following comparison: for both sectors we compare estimation of the traditional Phillips-curve equation, in which the parameter ω is set to 0 to shut off the relative price channel, with the estimation of the specification implied by our model. Table 8 summarizes the results of the equation (25) estimation for the full sample 1993–2012, for the

Figure 4. Plot of Price, Unit Labor Cost, and Relative Price for the Manufacturing Sector and the Non-farm Business Sector



Note: All variables are in logs and demeaned.

first part of the sample 1993–99, and for the last part of the sample 1999–2012. The split is again chosen consistent with the break identified in figure 3. Focusing first on the full sample and on the benchmark case of the traditional AS equation ($\omega = 0$), we obtain an estimate of k equal to 0.007 for the non-farm business sector, which implies a high degree of price rigidity—close to twelve quarters for a model with a common labor market and a moderate value, and close to six quarters for a model with firm-specific labor market.[17] These results suggest a higher degree of price rigidity than that found

[17]With a firm-specific labor market, the definition of k should also include a factor $(1 + \eta\bar{\sigma})$, where η is the inverse of the Frisch elasticity of labor supply.

Table 8. Estimates of k and ω in Equation (25) for the Manufacturing and Non-farm Business Sector

	Manufacturing Sector		Non-farm Business Sector	
	(1)	**(2)**	**(3)**	**(4)**
Full Sample 1993–2012				
k	0.000 (0.0016)	0.015 (0.0567)	0.007 (0.034)	0.034 (0.056)
ω	0	0.21 (0.30)	0	0.04** (0.020)
Sample 1993–99				
k	0.000 (0.0014)	0.001 (0.0268)	0.001 (0.0069)	0.021 (0.1707)
ω	0	−0.08 (0.468)	0	0.04 (0.111)
Sample 1999–2012				
k	0.000 (0.0029)	0.1 (0.2622)	0.008 (0.0385)	0.035 (0.0602)
ω	0	0.34 (0.306)	0	0.04** (0.0207)

Notes: In columns 1 and 3, ω is restricted to be equal to zero. Data are quarterly. Three different samples are considered: 1993–2012, 1993–99, and 1999–2012. Standard errors are in parentheses. The "stars" next to the sector's Roman numeral refer to a Chow test on the significance of the break date.

by Sbordone (2002), which covers a different sample. However, the estimated coefficient is not significantly different from zero. This is not surprising and is in line with the arguments of Fuhrer (2009) related to the difficulties of identifying the New Keynesian Phillips curve. We then repeat the same restricted ($\omega = 0$) estimation for the manufacturing sector on the full sample. Here we get the following estimates: $k = 0$ and then $\phi_1 = 1$. This result confirms the visual inspection obtained through figure 4. A value of k equal to zero in (27) implies that the lagged price performs better, based on our estimation criterion, in fitting the current price. Moreover, this shows that equation (25) can no longer be interpreted as the appropriate Phillips curve, as discussed also in Fuhrer (2009). Therefore, the traditional AS equation does not fit well data for the manufacturing sector.

We then perform the unrestricted estimation on the full sample and include the relative price channel ($\omega \neq 0$). We find that this channel is important for both sectors and, in particular, for the non-farm business sector. Now, the slope of the AS equation increases to 0.015 for the manufacturing sector and to 0.034 for the non-farm business sector. The latter value is now consistent with the results of the literature and with a degree of rigidity around three quarters as found in micro studies. Most important, the point estimate of ω is positive in both sectors and greater in the manufacturing sector. However, it is significant only for the non-farm business sector. Interestingly, when we look at the non-farm business sector, the positive sign becomes significant on the second part of the sample. In the first part of the sample all the coefficients perform poorly for both sectors.

These results support the importance of the relative price channel in explaining the dynamic of prices. This is true mostly for the second part of the sample when globalization plays a major role. Our results indeed shed light on the possible reasons for which traditional New Keynesian AS equations often provide erratic and insignificant results. We find a reduction of more than 70 percent in the criterion $\sum_{t=1}^{T} \varepsilon_t^2/T$ when we allow for a non-zero ω in the estimation of the AS equation, for both sectors. Relative prices as well as firms' market shares might therefore provide the missing link.

Guerrieri, Gust, and Lopez-Salido (2010), by comparing GMM estimations for an unrestricted—including relative prices—and a restricted specification of the AS, also find evidence that foreign competition plays an important role in accounting for the behavior of inflation in the traded goods sector. Their model, however, neglects any possible role that globalization might have on the slope of the Phillips curve. Our results confirm the importance of the relative price channel, even though we use different data and estimation techniques. In our case the combination of the model analysis, which carries sound microfoundations of the firms' strategic behavior, and of the estimation results adds crucial insights in interpreting the role of the relative price. The role of external factors is not limited to deflationary shifts of the AS curve but is crucial also for the sensitivity of prices to external conditions.

7. Conclusions

Much discussion has been devoted in recent years to the effects of globalization. While the globalization process takes different forms, we focus on one particular aspect, which is the surge in the fraction of firms selling abroad. Competition in international markets renders the pricing decision of firms more dependent upon foreign factors and hence reduces the dependence of inflation on the domestic slack. This increased link between domestic inflation and global factors occurs through two main channels. First, there is an increase in the impact of import prices on the overall price index, due to an increase in the number of foreign products in domestic markets. Second, there is an increase in the dependence of the pricing strategies of domestic firms upon foreign components, due to the increase in competition with foreign firms. Interestingly the reduced form of the Phillips curve changes. Indeed it shifts with respect to relative price movements. Moreover, the sensitivity of inflation to marginal costs changes with respect to foreign firms' penetration. Finally, as far as firms' pricing decisions are affected by the relative market shares between domestic and foreign firms competing in the same destination market, the degree of exchange rate pass-through rises with an increase in the number of foreign competitors. We test the model results with an empirical analysis based on U.S. sectors belonging to HS classification. We find evidence of an increase in the degree of pass-through in the majority of the sectors considered. Moreover, estimation of the AS equation provides evidence for the importance of the relative price channel in accounting for the dynamic of inflation as emphasized by our model.

The dependence of inflation upon global factors might have important implications for the conduct of monetary policy, as it might reduce the leverage that central bankers have in controlling prices. Recent studies based on DSGE analysis (see Bouakez and Rebei 2008) have also emphasized the role of monetary policy in explaining changes in pass-through. We leave these topics for future research.

Appendix. Data

Pass-Through Analysis

Sectoral import prices data are taken from the Bureau of Labor Statistics (BLS). The indexes are industry-specific multilateral import prices following the one-digit harmonized system (HS) classification. The data used have monthly frequency on the sample 1993:M12–2012:M2.

Table 9 shows the sectors that are considered.

The nominal effective exchange rate, the commodity price index, and the three-month U.S. Treasury bill rate are taken from Datastream with the respective codes 741111577, WDI76ACDF, and USGBILL3.

Table 9. Sectors and Their HS Classifications

Sectors	**HS Sectors**
Live Animals and Animal Products	I
Vegetable Products	II
Prepared Foodstuffs, Beverage, and Tobacco	IV
Mineral Products	V
Products of the Chemical or Allied Industries	VI
Plastics and Articles Thereof	VII
Raw Hides, Skins, Leather, Furskins, etc.	VIII
Wood, Wood Charcoal, Cork, etc.	IX
Wood Pulp, Recovered Paper, and Paper Products	X
Textiles and Textile Articles	XI
Headgear, Umbrellas, Artificial Flowers, etc.	XII
Stone, Plaster, Cement, etc.	XIII
Pearls, Stones, Precious Metals, Imitation Jewelry, and Coins	XIV
Base Metals and Articles of Base Metal	XV
Machinery, Electrical Equipment, etc.	XVI
Vehicles, Aircraft, Vessels, and Associated Transport Equipment	XVII
Optical, Photo, Measuring, Medical and Musical Instruments and Timepieces	XVIII
Miscellaneous Manufactured Articles	XX

Data on sectoral import share from China are taken from the U.S. International Trade Commission (USITC) website. Yearly data on sectoral imports by the HS system for the period 1992–2012 (through February) are taken from the U.S. Census Bureau. The penetration index is calculated as the ratio between Chinese sectoral imports to the United States and total sectoral imports to the United States. The yearly penetration index is then matched with the pass-through coefficients obtained through the rolling-window estimates. The average of the starting point and the end point of the rolling window was used in order to assign a year and a month to the estimate. Then an annual time series was constructed using the end-of-year data.

Sectoral index of concentration data are taken from the Economic Census: concentration ratios are available for the years 1997, 2002, and 2007. In particular, the Herfindahl-Hirschman Index for the fifty largest companies from the Economic Census has been used. The available data for the three years mentioned above are assumed to be valid also in the years following the respective census if no new data has arrived. Data are available for each three-digit NAICS sector. Since the rest of the data sample follows the HS classification, we had to match the sectors of the NAICS classification with the rest. The matching was chosen as follows: sector IV matched with 311/312, V with 324, VI with 325, VII with 326, VIII with 316, IX with 321, X with 322, XI with 313/314/315, XIII with 327, XV with 331/332, XVI with 333/335, XVII with 336, XVIII with 324, and XX with 337/339. Sectors I and XIV were dropped since they could not be matched with the NAICS classification.

Aggregate Supply Analysis

The data for prices and unit labor costs for the manufacturing sector and non-farm business sector are from BLS and are available on a quarterly basis. The series for import prices is constructed from the HS import indexes at one digit, excluding sectors III and XIX for missing data. The original series have monthly frequency; hence, in order to obtain a quarterly series, the average value of three months for each quarter has been considered. Data on sectoral import prices have been aggregated into a single import price using the Relative Importance Index of tables 3 and 5 from the historical tables of U.S. Import and Export Price Indexes of the BLS of April 2012.

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The Demand for Short-Term, Safe Assets and Financial Stability: Some Evidence and Implications for Central Bank Policies*

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In this paper, we consider the extent to which central banks can improve financial stability and manage maturity transformation by the private sector through their ability to affect the public supply of short-term, safe instruments (STSI). First, we provide new evidence on two key ingredients for there to be a role for policy: the extent to which public and private short-term debt are substitutes, and the relationship between the supply of STSI and the money premium, stemming from their liquid, short-term, and safe nature. Then, we discuss potential ways a central bank could use its balance sheet and monetary policy implementation framework to affect the quantity and mix of short-term liquid assets available to financial market participants.

JEL Codes: G12, G18, G2, E4, E5.

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1. Introduction

Short-term, safe instruments (STSI) appear to carry a money premium that lowers their yields. This premium stems from their liquid, short-term, and "safe" nature—their money-like attributes. Greenwood, Hanson, and Stein (2015) present evidence that this money premium is especially large at the short end of the Treasury yield curve. They argue that this premium reflects the extra "moneyness" of short-term Treasury bills, above and beyond the well-established "convenience premium" that reflects the liquidity and safety attributes of both shorter-term and longer-term Treasury securities.[1] In particular, because Treasury bills provide a certain return within a short time frame, they are an attractive asset for money funds or corporate cash managers.

While public instruments—government debt securities and central bank liabilities—comprise an important part of the supply of STSI, short-term, high-quality privately issued securities also possess attributes of STSI, though perhaps to a somewhat lesser degree than public securities. As noted in Gorton (2010), Gorton and Metrick (2012), and Stein (2012), private financial intermediaries take advantage of this money premium when they issue certain types of collateralized short-term debt, such as asset-backed commercial paper (ABCP), or engage in repo transactions.[2] They argue that this "private money creation" was a big part of the growth in the shadow banking sector in the years preceding the financial crisis, where seemingly safe maturity and liquidity transformation led to the run-like behavior in financial markets observed during the crisis.[3]

[1]The money premium is different from a liquidity premium. For example, short-term Treasury bills are more liquid than Treasury notes and bonds with the same remaining maturities and consequently have lower yields (Amihud and Mendelson 1991). However, both are similarly money-like at short horizons: A money-market fund can hold a three-month Treasury bill as well as a Treasury note with three months remaining maturity, even if the latter is much less liquid.

[2]Lucas (2013) argues that the interaction of Regulation Q and the U.S. inflation of the 1970s drove business deposits out of the regulated commercial banks and into the shadow banking sector.

[3]See a detailed discussion of the shadow banking system and financial stability in Tarullo (2012), available at http://www.federalreserve.gov/newsevents/speech/tarullo20120612a.htm.

In this paper, we take the demand for STSI as given and analyze the extent to which a central bank can improve financial stability through its ability to affect the public supply of STSI. For example, a central bank could use the size and composition of its balance sheet to affect the supply of STSI, thus potentially influencing the money premium and the incentives to create private STSI. Such an approach could be complementary to macroprudential policies targeted to limit the financial stability risks associated with the private issuance of STSI. It would also be similar to an approach where the Treasury could tilt its issuance more toward short maturities and supply more Treasury bills as discussed in Greenwood, Hanson, and Stein (2015).

The first part of the paper provides new evidence regarding the money-like attributes of STSI that complements the existing literature, focusing on two key ingredients that are necessary for there to be a potential role for policy: the extent to which public short-term debt and private short-term debt might be substitutes, and the relationship between the supply of STSI and the money premium.[4] First, we extend the existing literature that analyzes the degree to which quantities of public and private STSI appear to substitute for one another by looking across a broader set of private STSI. We find that several money-market instruments—such as financial and non-financial commercial paper (CP), asset-backed CP, and time deposits—exhibit a strong negative relationship with the amount of Treasury bills outstanding. Using vector autoregressions, we also show that private STSI tend to respond within two or three months to shocks to the amount of public STSI, and the dynamic effects are stronger for financial instruments issued by institutions with the most flexibility to adjust to changing money premiums, namely, financial institutions.

Second, we provide new evidence on the mechanism through which the supply of public STSI might crowd out short-term borrowing by the financial sector. Consistent with the hypothesis that

[4]While we take the demand for STSI as given, it is important to note that this demand is likely to continue to be high and even grow, given upcoming regulatory changes such as Dodd-Frank Act requirements that certain over-the-counter derivatives are centrally cleared and the Basel III liquidity regulations. This increased demand will further add to the potential sources of pressures going forward.

this substitution is brought about by adjustments in the equilibrium price of safety, we find that an increase in the supply of Treasury bills leads to a decrease in the spread between the yields on private STSI and Treasury bills. We also present a new way to measure the money premium in terms of the realized excess return on Treasury bills. Specifically, if the money premium results in very low yields at the front of the curve, then buying bills with longer maturities and holding them as they become more money-like should be profitable. Using CUSIP-level data for Treasury bills, we find that this holding return increases steeply at the very short end of the yield curve and diminishes as maturities grow and the securities become less money-like, consistent with the z-spread measured by Greenwood, Hanson, and Stein (2015).[5] We then show that this positive excess return of longer-maturity bills is negatively related to the supply of Treasury bills. This effect is more pronounced at the short end of the yield curve, a result that is consistent with the view that shorter Treasury bills have the most money-like attributes. We also summarize discussions with several major issuers of, and investors in, very short-term financial instruments, who, for the most part, expressed some skepticism about the hypothesis that increasing the supply of Treasury bills results in a reduced supply of private money-like instruments.

Nevertheless, overall, our empirical evidence appears to be broadly consistent with the substitution hypothesis, as well as with the results from the earlier literature that studies the relationship between the supply of government debt and interest rate spreads. Greenwood, Hanson, and Stein (2015) show that a 1-percentage-point increase in the ratio of Treasury bills to GDP (roughly one-half of a standard deviation) leads to a 5.6-basis-point narrowing in the two-week z-spread. They also find that the effect is strongest for very short-term Treasury bills, even after controlling for potential endogeneity between money demand and Treasury-bill issuance. Gorton, Lewellen, and Metrick (2012) provide some rough evidence that government debt and bank debt may indeed be substitutes in meeting the demand for STSI. Krishnamurthy and Vissing-Jorgensen (2012)

[5] To measure the money premium, Greenwood, Hanson, and Stein (2015) define the z-spread as the difference between actual short-term Treasury-bill yields (with maturities from one to twenty-six weeks) and fitted yields, where the fitted yields are based on a flexible extrapolation of the Treasury yield curve from Gurkaynak, Sack, and Wright (2007).

show that the spread between second-tier and first-tier CP falls when the supply of Treasury securities expands, which suggests that top-tier CP is indeed a potential substitute for Treasury securities. Sunderam (2015) analyzes the extent to which ABCP is money-like and shows that positive shocks to money demand increase the spread between ABCP and Treasury-bill yields, and increases in Treasury-bill supply decrease this spread. Moreover, he shows that the financial sector increases their issuance of ABCP in response to positive money demand shocks.

The second part of the paper then provides a discussion of policy options in light of these results. Our finding that there seems to be a relationship between public and private STSI has potential implications for monetary policy, suggesting that the monetary policy framework and implementation may influence the creation of private STSI for a given demand. In particular, if the relationship between public and private short-term debt issuance is causal and robust, greater provision of public STSI by a central bank may result in smaller issuance of private STSI and lower levels of associated liquidity and maturity transformation, potentially improving financial stability. For example, a central bank could boost the supply of public STSI by keeping a relatively large balance sheet and conducting its monetary policy using a floor system, where large holdings of longer-term assets are financed by correspondingly large amounts of reserve balances that are, in turn, safe and liquid assets for financial institutions. Alternatively, a central bank could also boost the supply of STSI while still operating monetary policy using a corridor framework, rather than a floor framework, by, for example, financing its large asset holdings with a different composition of liabilities—a relatively small amount of bank reserve balances and a large volume of reverse repurchase agreements with non-bank counterparties. In this regard, we find that there is a strong negative correlation between the outstanding quantity of Treasury bills and the quantity of overnight reverse repos invested at the Federal Reserve in 2014, suggesting that reverse repo agreements with a central bank are very similar to Treasury bills as a form of public supply of STSI.

The remainder of the paper is organized as follows. Section 2 contains our empirical results. Section 3 provides some context for these findings based on discussions with market participants. Section 4 discusses policy options. The final section offers concluding remarks.

2. Empirical Analysis

In this section, we provide new evidence that complements the existing literature on the three key ingredients that are necessary for there to be a role for policy in managing the implications of demand for STSI: the extent to which public short-term debt and private short-term debt might be substitutes, the dynamics of the money premium, and the relationship between the money premium and the supply of STSI.

In particular, a key argument in the literature is that public and private assets of this type are, to some degree, substitutes in meeting the demand for STSI, although for a number of reasons the public securities are preferable to private ones. As a result, the money premium on a particular set of safe and liquid instruments will, in turn, depend in part on the total supply of STSI, including the supply of public STSI. For instance, when there are more Treasury bills, the money premium is reduced for all private STSI as well as for Treasury bills (that is, yields are higher), because both public and private short-term debt instruments meet the demand for STSI. If, in addition, private issuance of short-term debt responds positively to this money premium, then increases in the issuance of Treasury bills should also lead to a decline in private short-term debt issuance.

This reasoning suggests the following testable hypotheses about an exogenous shift in the supply of Treasury bills:

- Increases in the supply of Treasury bills should lead to a reduction in the quantity of private STSI.
- Increases in the supply of Treasury bills should lead to a decrease in the money premium on Treasury bills (higher yields).
- Increases in the supply of Treasury bills should lead to a decrease in the money premium on private STSI (higher yields).
- Increases in the supply of Treasury bills should cause the yield on Treasury bills to increase *by more* than the increase in the yield on private STSI, narrowing the spread between the yields on private STSI and Treasury bills. Because of the greater moneyness of Treasury bills relative to private STSI, the yields on Treasury bills should be more responsive to changes in supply.

The analysis below provides some support for these hypotheses.

2.1 The Supply of Treasury Bills and Private Short-Term Debt Creation

Tables 1 and 2 report the results of regressions of the outstanding amounts of selected money-market instruments (as a share of nominal GDP) on the outstanding amounts of current (table 1) or lagged (table 2) Treasury bills (divided by nominal GDP) using monthly data. The starting period of the analysis varies by instrument, but we end the sample period in 2007 so that our results capture the dynamics that prevailed before the crisis. We include month and year fixed effects to control for seasonal effects and time trends. The private money-market instruments that we consider are as follows: all financial CP, which includes issuance by financial companies as well as asset-backed CP; all non-financial CP; total time deposits for banks and thrifts; financial CP alone; ABCP alone; and non-Treasury assets of prime money-market funds.[6] In each case, an increase in the amount of Treasury bills is associated with a material decline in the amount of the private money-market instrument.[7] The effect is statistically significant for all instruments, with the exception of prime money-market fund assets.

It is important to understand how the changes in private STSI in response to changes in Treasury bills are affecting private institutions. One possibility is that the money premium primarily affects the type or maturity structure of the liabilities that financial institutions issue, but that total liabilities are not greatly influenced. A second possibility is that financial institutions take advantage of lower financing costs afforded by a higher money premium to expand their liability base. We provide some evidence regarding this question by looking at large U.S. domestic banks. We first repeat the regressions in table 2 to verify that the large time deposits of these

[6] All non-financial CP combines all the CP instruments, which allows us to construct a consistent time series dating back to late 1976.

[7] We also looked at the effect of changes in the outstanding amounts of longer-term Treasury securities. In some cases, larger outstanding amounts of these securities were also associated with reductions in the outstanding amounts of private money-market securities. However, the effects were smaller than for Treasury bills and the effect was statistically significant for fewer types of private securities.

Table 1. Levels Regression, Monthly Frequency: Private Debt/GDP on Treasury Bills/GDP

	(1) All Financial CP	(2) All Non-financial CP	(3) Total Time Deposits	(4) Financial CP	(5) ABCP	(6) MMR Assets – Treasury Securities
Treasury Bills/GDP	−0.306***	−0.127***	−0.465***	−0.371***	−0.196	−0.130
	(0.0434)	(0.0260)	(0.0526)	(0.0557)	(0.109)	(0.178)
Constant	44.40***	17.28***	102.0***	76.51***	76.50***	65.12***
	(3.576)	(2.226)	(5.257)	(4.437)	(9.107)	(17.64)
Observations	368	368	374	78	78	150
R^2	0.996	0.972	0.972	0.932	0.928	0.976

Notes: Each column represents a different left-hand-side variable corresponding to a different definition of private debt. "All Financial CP" is the sum of "Financial CP" and "ABCP." The sample period is 1976 to 2007 for columns 1 and 2, 1975 to 2006 for column 3, 2001 to 2007 for columns 4 and 5, and 1995 to 2007 for column 6. All of the regressions include month and year fixed effects. Standard errors are in parentheses. * denotes $p < 0.05$; ** denotes $p < 0.01$, and *** denotes $p < 0.001$.

Table 2. Levels Regression, Monthly Frequency: Private Debt/GDP on *Lagged* Treasury Bills/GDP

	(1) All Financial CP	(2) All Non-financial CP	(3) Total Time Deposits	(4) Financial CP	(5) ABCP	(6) MMR Assets – Treasury Securities
Treasury Bills/GDP (Lag)	−0.312***	−0.136***	−0.464***	−0.360***	−0.252*	−0.239
	(0.0432)	(0.0265)	(0.0501)	(0.0645)	(0.118)	(0.184)
Constant	45.34***	18.24***	102.2***	76.10***	81.31***	76.06***
	(3.661)	(2.287)	(5.044)	(5.248)	(9.925)	(18.40)
Observations	368	368	373	78	78	150
R^2	0.996	0.973	0.974	0.923	0.930	0.976

Notes: Each column represents a different left-hand-side variable corresponding to a different definition of private debt. "All Financial CP" is the sum of "Financial CP" and "ABCP." The sample period is 1976 to 2007 for columns 1 and 2, 1975 to 2006 for column 3, 2001 to 2007 for columns 4 and 5, and 1995 to 2007 for column 6. All of the regressions include month and year fixed effects. Standard errors are in parentheses. * denotes $p < 0.05$; ** denotes $p < 0.01$, and *** denotes $p < 0.001$.

Table 3. Levels Regression, Monthly Frequency: Liabilities of Large Domestic Banks to GDP on *Lagged* Treasury Bills/GDP

	(1) Large Time Deposits	(2) All Liabilities
Treasury Bills/GDP	−0.032*	0.075
(Lag)	(0.014)	(0.069)
Constant	−18,167	−57,270
	(13,903)	(147,085.2)
Observations	258	258
R^2	0.997	0.989

Notes: The sample period is 1986 to 2007. All of the regressions include month and year fixed effects. Estimation also adjusts for first-order autocorrelation. Standard errors are in parentheses. * denotes $p < 0.05$; ** denotes $p < .01$.

institutions respond similarly to total time deposits. We then test whether total liabilities of these institutions respond to changes in Treasury bills.

The results are shown in table 3. As shown in column 1, similar to total time deposits, we find that the large time deposits of large domestic banks decline relative to GDP when Treasury bills outstanding increase relative to GDP. However, as shown in column 2, we do not find that total liabilities change with Treasury bills outstanding. This result is robust to the inclusion of a variety of economic controls, such as the unemployment rate, federal funds rate, and inflation rate. This finding suggests that the moneyness premium has stronger effects on the maturity structure or types of debt issued by financial institutions than on the amount of debt. It is also similar to the argument in Greenwood, Hanson, and Stein (2010) that corporate debt maturity responds to the maturity structure of outstanding government debt.

To improve our understanding of the dynamics of the relationship between outstanding amounts of Treasury bills and private safe and liquid assets, we estimated a series of vector autoregressions (VARs). These VARs allow us to investigate the timing of the responses of various money-market instruments to changes in the outstanding amount of Treasury bills in a setting that also allows us to control for other factors, such as the state of the economy, which could also affect issuance of money-market instruments and Treasury securities. Furthermore, we can explore the dynamic impact of an exogenous innovation to the supply of short-term Treasury securities.

In all of our VAR specifications, the dependent variables are the growth of Treasury bills outstanding and the growth of a particular money-market instrument. We order these variables so that the growth of Treasury bills can affect the growth of the money-market instrument contemporaneously but not the other way around.[8] For most specifications, we use the same monthly data as in the univariate regressions (continuing to focus on the pre-2007 period). The different specifications include an increasing number of controls, starting with only lags of the dependent variables, then adding monthly dummies (to control for seasonal effects), and finally adding macroeconomic controls as exogenous factors in the VAR alongside the monthly dummies (unemployment, growth of industrial production, and personal consumption expenditures (PCE) inflation).

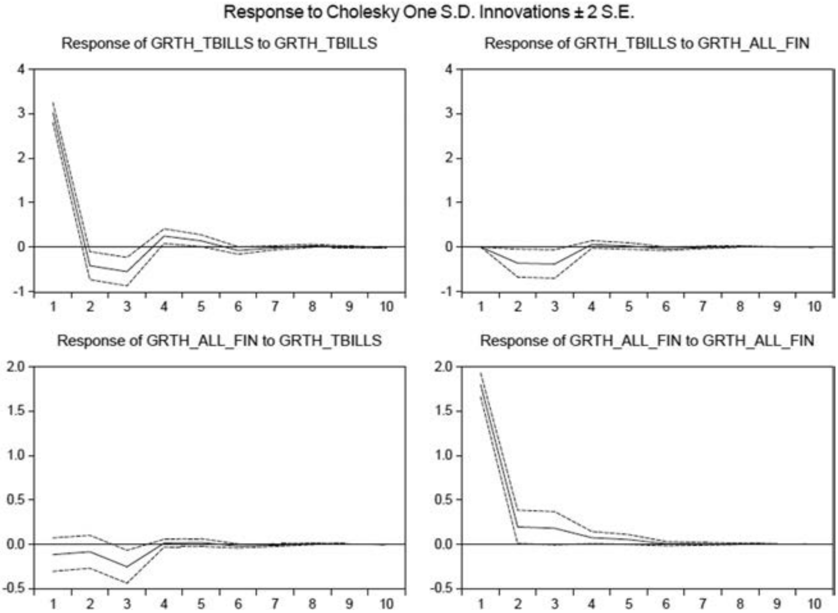
Results for these three specifications using all financial CP are shown in figures 1 through 3. In general, as shown in the bottom-left panel of all of the figures, we find that an increase in the growth rates of Treasury bills tends to depress the growth rates of financial CP over the following two months. We find a similar response when using the growth of large time deposits (not shown). We do not find a significant response for the growth of non-financial CP or in the growth of money fund assets (excluding Treasury securities). The findings may be due to financial institutions, which tend to have some of the most flexibility in terms of managing their liabilities, having the strongest response to shifts in bill issuance.[9]

These results are broadly consistent with those from the levels regressions and with the hypothesis that increases in Treasury

[8]In some cases, especially when the monthly dummies are not included, we find that a shock to financial CP affects the growth rate of Treasury bills. It is not clear how to interpret this finding. It is possible that there is some underlying factor affecting both series. Consistent with this notion, when monthly dummies and macroeconomic factors are included, this effect is notably diminished.

[9]These results are generally robust to using weekly data, although in the weekly VARs the peak response of private issuance to Treasury-bill growth is typically estimated to be a few weeks out, rather than two or three months as in the monthly VAR.

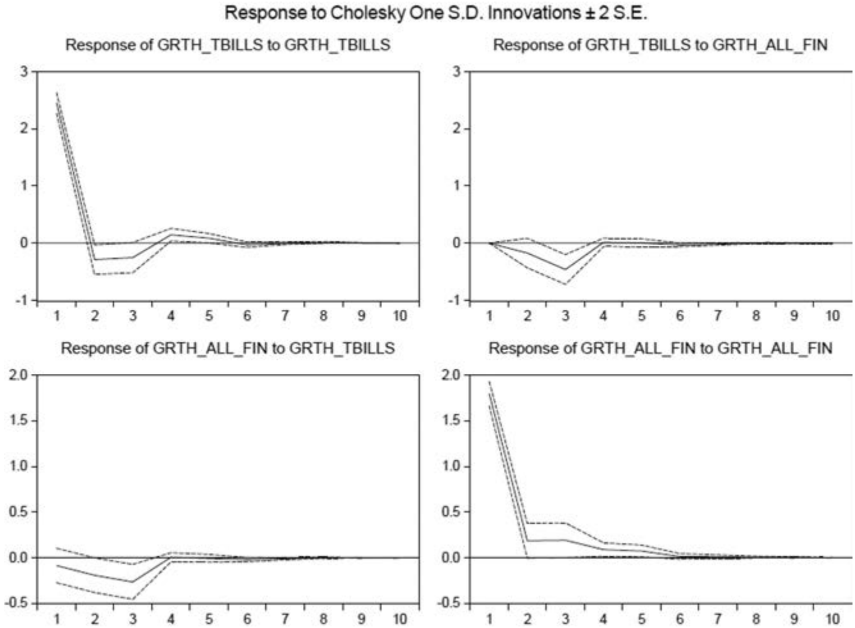
Figure 1. Growth of Treasury Bills and All Financial CP (no controls)



Notes: This figure presents the impulse response function obtained from a VAR of the growth of Treasury bills and the growth of all financial commercial paper (CP). The top (bottom) panels display the response of the growth of Treasury bills outstanding (growth of all financial CP) to a one-standard-deviation shock to each of the VAR endogenous variables. The dotted lines are 95 percent confidence bands. The VAR is estimated using monthy data for the period of 1976 to 2007.

bills outstanding result in a reduction in the growth of other money-market instruments. In conversations with market participants (described below), they reported that issuance of negotiable CDs tended to occur when loan growth exceeded deposit growth. Including loan growth directly in our level regressions is problematic, as loan growth is plausibly endogenous; if funding conditions are favorable and issuing negotiable CDs is relatively cheap, then the banks may ease lending terms and boost loan growth. Our VAR regressions get at this issue to some extent by including measures of output growth and unemployment rates which are likely correlated with loan demand but are more plausibly exogenous with respect to

Figure 2. Growth of Treasury Bills and All Financial CP (includes only month dummies)

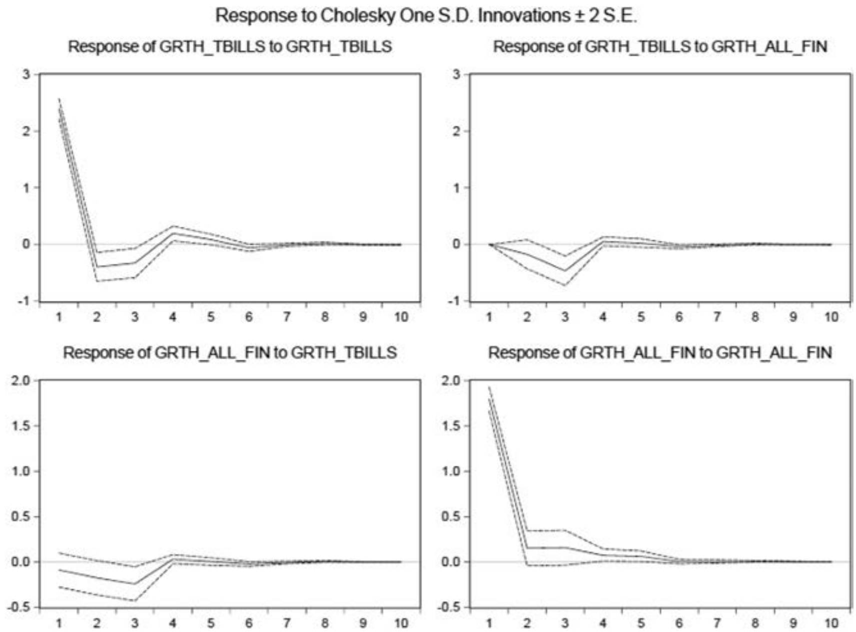


Notes: This figure presents the impulse response function obtained from a VAR of the growth of Treasury bills and the growth of all financial commercial paper (CP). The VAR includes month dummies. The top (bottom) panels display the response of the growth of Treasury bills outstanding (growth of all financial CP) to a one-standard-deviation shock to each of the VAR endogenous variables. The dotted lines are 95 percent confidence bands. The VAR is estimated using monthy data for the period of 1976 to 2007.

the decisions of any particular bank. Nevertheless, in untabulated regressions, we tried adding loan growth to the regressions reported in table 1 and table 2, and the qualitative results are very similar.[10] There was minimal effect from adding this variable to the VARs.

[10]The coefficients on the impact of Treasury bills to GDP on issuance of different types of money-market securities reported in table 1 and table 2 typically become slightly smaller. For example, the coefficient on Treasury bills in table 1, column 1 falls from −.306 to −.257 but remains highly significant. The ratio of bank loans to GDP has a positive and significant effect on issuance of money-market instruments.

Figure 3. Growth of Treasury Bills and All Financial CP (includes month dummies and macro factors—unemployment, IP growth, and inflation)



Notes: This figure presents the impulse response function obtained from a VAR of the growth of Treasury bills and the growth of all financial commercial paper (CP). The VAR includes the unemployment rate, the growth of industrial production, and PCE inflation alongside month dummies as exogenous controls. The top (bottom) panels display the response of the growth of Treasury bills outstanding (growth of all financial CP) to a one-standard-deviation shock to each of the VAR endogenous variables. The dotted lines are 95 percent confidence bands. The VAR is estimated using monthy data for the period of 1976 to 2007.

2.2 Supply of Treasury Bills and the Money Premium

The evidence in the previous section suggests that Treasury bills and the private STSI are substitutes. One way that the supply of Treasury bills could crowd out private STSI is by affecting the equilibrium price of safety. To examine this hypothesis, we first estimate the effect of the growth rate of Treasury bills on money-market rates and spreads. According to our hypothesis, greater availability of Treasury bills would result in a smaller money premium, thus narrowing the spread between yields on instruments such as financial CP and Treasury bills, as the latter provide more monetary services per dollar invested and thus have a higher and more sensitive money premium.

2.2.1 Treasury-Bill Supply and the Spreads of Private STSI Yields over Treasury-Bill Yields

We estimate VARs involving rates and spreads using weekly data, as we expect prices to respond fairly quickly. We focus on the spread between rates on thirty-day financial commercial paper and on the four-week Treasury bill, as the money premium in Treasury bills tends to be more pronounced for shorter maturities.[11] Since four-week Treasury bills have not been issued for quite as long a time, we confine our sample period to October 2001 to June 2007.[12] Consistent with the STSI hypothesis, we find some evidence that increased Treasury-bill issuance results in a narrowing of the spread between financial CP and Treasury-bill rates (figure 4, bottom panel).[13]

2.2.2 Treasury-Bill Supply and the Excess Holding Return on Treasury Bills

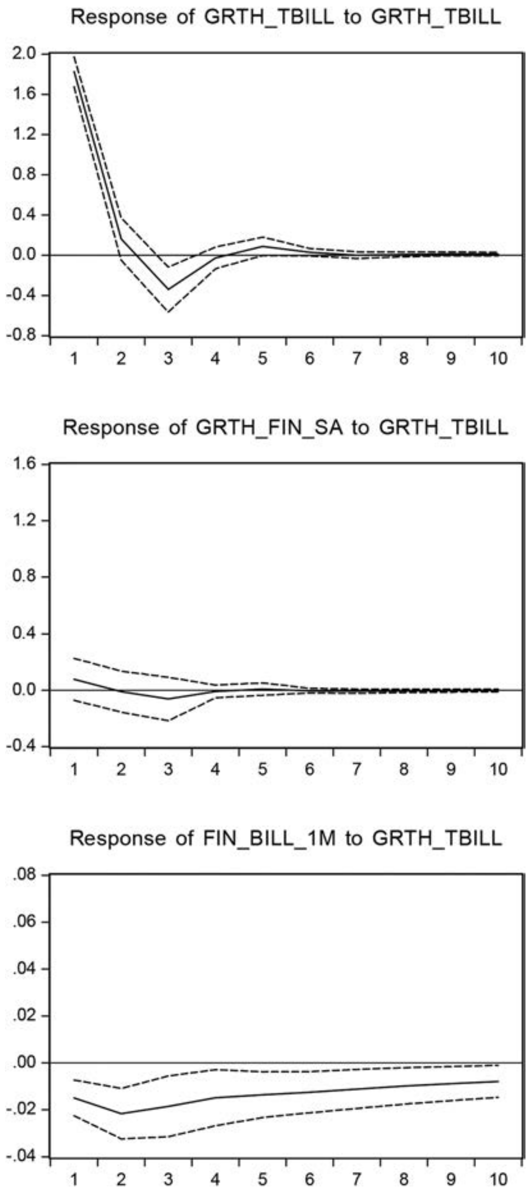
The preceding analysis focused on evidence of money premia by looking at the spreads and substitutability between private short-term safe assets and public short-term safe assets. However, it is possible that a money premium may also be evident from the Treasury curve alone. Greenwood, Hanson, and Stein (2015) present some evidence

[11] We use thirty-day financial commercial paper, as these instruments were found above to be quite responsive to changes in Treasury bills. Using other private rates, such as those on negotiable certificates of deposit, relative to Treasury bills produced similar results.

[12] With the shorter sample period, we include monthly dummies in the VARs but do not include the macroeconomic variables.

[13] We also looked at the spread between rates on three-month commercial paper and Treasury bills, but did not find any robust relationship. With the three-month rates, we can use monthly data and extend the series back in time much further. In this case, the effect has a negative sign but is only statistically significant after four months, a much longer time lag than we would expect.

Figure 4. Growth of Treasury Bills and Interest Rate Spreads (includes month dummies)



Notes: This figure presents the impulse response function obtained from a VAR of the growth of Treasury bills, the growth of all financial commercial paper (CP), and the spread between rates on thirty-day financial commercial paper and on the four-week Treasury bill. The VAR includes month dummies as exogenous controls. Each panel displays the response of each variable in the VAR to a one-standard-deviation shock to the growth of Treasury bills outstanding. The dotted lines are 95 percent confidence bands. The VAR is estimated using weekly data from October 2001 through June 2007.

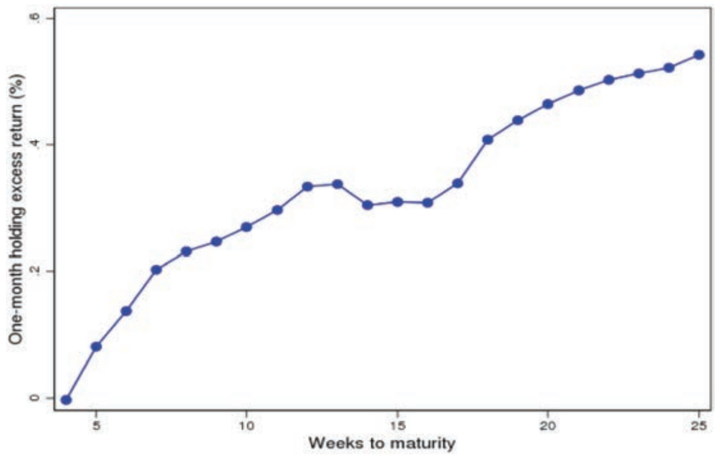
of this by showing that Treasury bills carry a money premium that lowers their actual yields relative to a fitted yield curve.[14] An alternative way to think of this money premium is in terms of the realized excess return on Treasury bills over a one-month holding period. If the premium results in very low yields at the front of the curve, then buying bills with longer maturities and holding them as they become more money-like should be profitable. In particular, the one-month holding return should be high relative to the overnight rate and should increase sharply but at a decreasing rate as maturities grow and the securities become less money-like. Figure 5 illustrates this point. The figure presents the average realized one-month holding-period return on a Treasury bill with n weeks to maturity in excess of the month-average one-week rate, calculated as follows:

$$xr^{(n)}_{t \to t+4} = \left(p^{(n-4)}_{t+4} - p^{(n)}_{t}\right) - r^{w}_{t-1 \to t+3}, \tag{1}$$

where $p^{(n)}_t$ is the log price of an n-week Treasury bill, and $r^{w}_{t-1 \to t+3}$ is the average one-week bill rate over the month. The statistics are computed using weekly security-level data on Treasury prices from the Federal Reserve Bank of New York's Price Quote System (PQS), and the holding-period return is measured in annual percentage points. As would be implied by the money premium hypothesis, this holding return is indeed concave—increasing steeply at the very short end of the yield curve. To be clear on the interpretation of the figure, it implies that the ex post realized return to buying and holding a three-month bill for one month is 34 basis points greater than that on one-week bills; the corresponding differential for buying and holding six-month bills for one month is 54 basis points. Relative to the risks involved, these are extremely large return differentials, far too large to be accounted for by standard risk/return-based asset pricing models.

[14]In particular, Greenwood, Hanson, and Stein (2015) capture the money premium as the difference between actual short-term Treasury bill yields (with maturities from one to twenty-six weeks) and fitted yields, where the fitted yields are based on a flexible extrapolation of the Treasury yield curve from Gurkaynak, Sack, and Wright (2007). They find that four-week bills have yields that are roughly 40 basis points below their fitted values; for one-week bills, the spread is about 60 basis points.

Figure 5. Average Excess One-Month Holding-Period Return to Buying Treasury Bills



January 1988–December 2007

Notes: This figure presents the average one-month holding-period return on a Treasury bill with n weeks to maturity in excess of the one-week rate, as defined in equation (1). The statistics are computed using weekly observations. The holding-period return is measured in annual percentage points, and it is computed using security-level data on Treasury prices from the Federal Reserve Bank of New York's Price Quote System (PQS).

To further explore if increases in the supply of Treasury bills lead to a decrease in the money premium of Treasury bills, we explore the relationship between the supply of Treasury bills and one-month holding excess returns at the front end of the yield curve. Specifically, we estimate the following regression:

$$xr^{(n)}_{t\rightarrow t+4} = \beta_0 + \beta_1 Bills/GDP_t + \mathrm{d}_t + \varepsilon_{t\rightarrow t+4}, \tag{2}$$

where $xr^{(n)}_{t\rightarrow t+4}$ is the one-month holding-period excess return on a Treasury bill with n weeks to maturity as defined in equation (1) above, and d_t is a vector of monthly dummy variables. The results from these regressions are shown in table 4 and figure 6, and the uniformly negative coefficients on the bill-supply term suggest that an increase in Treasury-bill issuance results in a decline in the money premium. Moreover, this effect is larger at the shorter

Table 4. Supply of Treasury Bills and the Money Premium

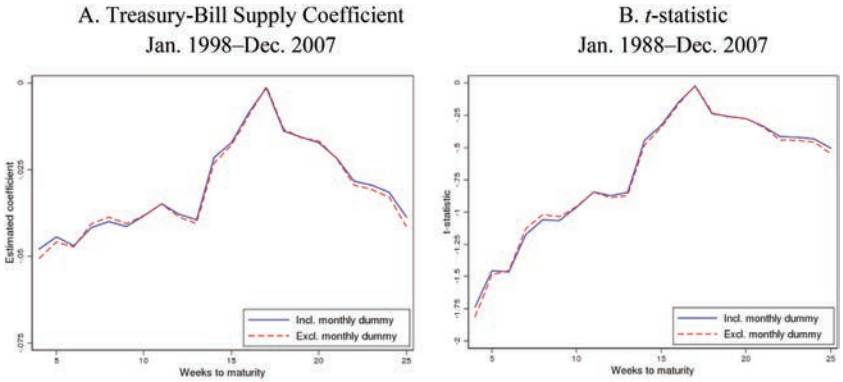
	Four Week	Five Week	Six Week	Ten Week	Thirteen Week
A. Sample January 1988–September 2012					
β_1	−0.014	−0.023	−0.029	−0.035	−0.035
t-stat	−1.235	−1.720	−2.048	−2.027	−1.674
$H_0 : \beta_1 \geq 0$					
p-value	0.109	0.043	0.020	0.021	0.047
B. Sample January 1988–December 2007					
β_1	−0.051	−0.046	−0.047	−0.038	−0.041
t-stat	−1.812	−1.485	−1.456	−0.959	−0.872
$H_0 : \beta_1 \geq 0$					
p-value	0.035	0.069	0.073	0.169	0.192

Notes: This table presents the estimated coefficient on Treasury bills along its t-statistic obtained from a regression of the one-month holding-period excess return on a Treasury bill with n weeks to maturity on the supply of Treasury bills as a share of GDP. The t-statistics are computed using Hodrick GMM correction for overlapping observations. The holding-period return is measured in annual percentage points using weekly observations, and the Treasury-bills-to-GDP ratio is measured in percentage points. The holding-period return is computed using security-level data on Treasury prices from the Federal Reserve Bank of New York's Price Quote System (PQS).

horizons where the instrument is more money-like. Both of these results are consistent with the money premium hypothesis.

These results should also be interpreted with care, however, as there are a variety of caveats and confounding factors. An important confounding factor, for example, is that Treasury-bill yields also reflect the variety of "special services" bills offer, which are importantly different from "money services." For example, a holder of a Treasury bill can use it as collateral in money-market or clearing transactions. This "specialness" suggests that the Treasury bills and central bank liabilities or private STSI may be only imperfect, partial substitutes. Extrapolating from our empirical results based on the pre-crisis period is also complicated by ongoing changes in the regulatory and supervisory environment that will affect the

Figure 6. Supply of Treasury Bills and the Money Premium



Notes: The left column displays the estimated coefficient on Treasury bills as a share of GDP and the right column displays its t-statistic obtained from a regression of the one-month holding-period excess return on a Treasury bill on the supply of Treasury bills as a share of GDP. The results are reported with and without monthly dummy variables as controls. The t-statistics are computed using Hodrick GMM correction for overlapping observations. The holding-period return is measured in annual percentage points, and the Treasury-bills-to-GDP ratio is measured in percentage points. The coefficients are computed using weekly observations. The holding-period return is computed using security-level data on Treasury prices from the Federal Reserve Bank of New York's Price Quote System (PQS).

demand and supply of STSI. For instance, the liquidity coverage ratio in Basel III bank regulatory rules may discourage the creation of private STSI by banks, the financial institutions found here to be the most responsive to changes in the supply of public STSI. Other regulatory changes, such as increased use of central clearing facilities and higher margin requirements for derivatives, will likely raise the demand for high-quality safe assets and may lead to an increase in private STSI (for example, as part of collateral optimization and transformation services). Until the regulatory changes are fully implemented, attempts to quantify the effect of changes in public STSI on private STSI will be challenging, and gauging the effect of policy on the money premium will be accordingly uncertain.

3. Discussions with Market Participants

To help evaluate whether the empirical results reported above accurately reflect the current relationship between the supply of Treasury bills and demand for private substitutes, we talked to several major issuers of, and investors in, very short-term financial instruments. If issuers of private short-term debt are systematically able to raise funds more cheaply when the amount of Treasury bills outstanding is lower, it would seem likely that they would pay attention to the Treasury-bill issuance calendar. Similarly, we were interested to see if investors in short-term debt reduce their demand for private debt in response to increased issuance of public debt.

3.1 Issuers

On the issuer side, we spoke with officials responsible for corporate funding at institutions that are major issuers of financial CP and certificates of deposit. Several of these issuers noted a change in liquidity risk management following the financial crisis that has resulted in a more opportunistic approach to CP issuance. In particular, they had revised up sharply their assessment of the liquidity risks associated with CP, and regulatory changes have made CP less attractive. Consequently, they expected to use CP less as a consistent source of funding. They also suggested that empirical results based on pre-crisis correlations might no longer hold.

Overall, the officials unanimously indicated that they never consider the Treasury-bill issuance calendar when deciding whether and when to issue CP and were generally skeptical of the hypothesis that greater Treasury-bill issuance would lead to reduced issuance of private short-term debt. A number of them characterized their decision to issue as driven primarily by differentials between loan growth and deposit growth, although they also noted that opportunistic issuance can be rate driven.

They did, however, point to some mechanisms through which Treasury-bill supply could influence private CP issuance. In particular, these issuers indicated that they do react to investor interest, or lack thereof, in their paper. If investor demand were influenced by Treasury-bill issuance, then CP issuance could be affected indirectly by Treasury-bill supply. In addition, they noted that their issuance can be influenced by conditions in the repo market: If repo rates are high, CP issuance might be delayed because CP rates would also be high. Because heavy Treasury-bill issuance—for example, around the tax season—can drive up repo rates by increasing dealer inventory and thus financing needs, opportunistic CP issuance in such circumstances would result in a negative correlation between Treasury bills and financial CP. At a longer frequency, they noted that when the economy is growing briskly, financial CP picks up because loan growth outstrips deposit growth, while Treasury-bill issuance may fall off because tax receipts go up and non-discretionary expenditures fall.

3.2 Investors

On the investor side, we spoke to important players in money markets. They noted that the demand for Treasury securities and high-quality assets in general continued to be very strong, and that they expected such demand to persist and possibly even increase as a result of various ongoing regulatory changes (for example, money-market fund reform, Basel III liquidity rules). They agreed that there was potentially some substitutability between public and private instruments. They added, however, that it might take an implausibly large change in yields to induce shifts in demand of economically meaningful magnitudes. For instance, in their view, an investor would always choose to invest in private STSI because it has a higher risk-adjusted yield, but an investor might also hold some Treasury bills to satisfy liquidity demands that cannot be met by private STSI. In that case, investors might increase or decrease the share of Treasury bills somewhat in response to relative yields but not by a large amount.

4. Policy Options

To the extent that there is a durable tendency for the money premium on STSI to increase (and yields to decline) when the demand for STSI rises, a central bank might decide to intervene by increasing the supply of STSI (and thus affect the money premium indirectly) to reduce the incentive for the shadow banking system to create such instruments and thus improve financial stability. This consideration may be especially relevant, as the demand for STSI is anticipated to increase in the future as a result of a number of regulatory changes, as mentioned above.

4.1 Maintain a Large Balance Sheet, with Either a Floor or a Corridor System

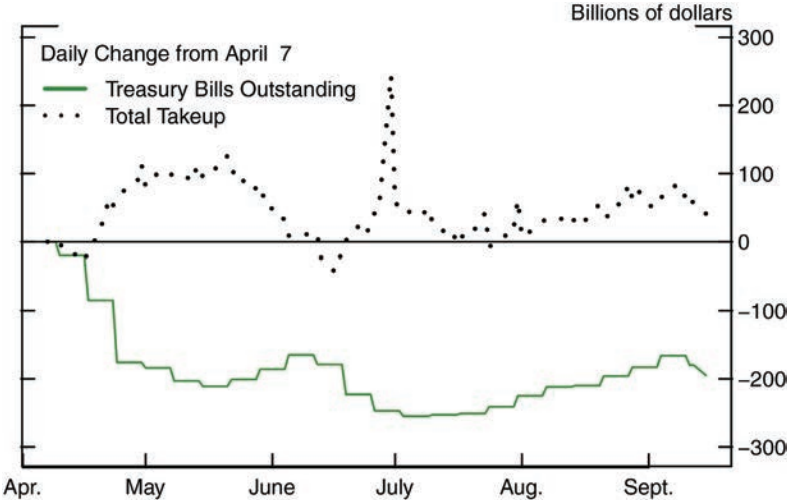
One policy that a central bank could implement, and that would permanently boost the supply of public STSI, would be to maintain a large balance sheet financed with central bank liabilities that are, in turn, safe and liquid assets for financial institutions. To execute such a policy, the central bank could conduct its monetary policy using a floor system with large holdings of less-liquid or longer-term assets financed by correspondingly large amounts of reserve balances. While reserve balances can only be held by depository institutions, the reserve balances might, in principle, satiate the demand of depository institutions for liquid assets. These depository institutions should, in turn, sell their other liquid assets, such as Treasury securities, to non-depository financial institutions.[15] Because the total supply of STSI would go up, the STSI premium should fall.[16]

Alternatively, the central bank could boost the supply of STSI while still operating monetary policy using a corridor, rather than a floor, framework. For example, the central bank could finance its large asset holdings with the relatively small amount of reserve balances (consistent with maintaining its policy tool in the middle of the corridor) while at the same time engaging in large volumes of reverse

[15] A central bank could also facilitate the transfer of increased liquidity benefits of elevated reserve balances to the non-bank sector by creating segregated cash accounts as described in Kirk et al. (2014). The accounts would enable banks to offer customers deposits that were completely collateralized by reserve balances and that are therefore completely safe. Such accounts would be a form of public STSI that could, in principle, displace private STSI.

[16] For example, the assets held by the Federal Reserve could simply be longer-term Treasury and agency securities. If the Federal Reserve further wished to maximize not only the public supply of safe short-term assets, but of safe assets more generally, it could hold as the primary asset on its balance sheet Term Auction Facility (TAF) loans rather than government securities. Banks would pledge illiquid assets to the discount window, so TAF lending would increase the availability of liquid assets for the financial system. However, this policy addresses a somewhat different set of issues—namely the total supply of available safe assets, rather than the supply of STSI specifically.

Figure 7. Change in the Supply of Treasury Bills and the ON RRP Take-Up



Note: This figure depicts the Treasury bills outstanding (solid line) and the Federal Reserve's full-allotment overnight reverse repurchase agreement (ON RRP) take-up.

repurchase agreements with non-bank counterparties. Reverse repurchase agreements with the central bank would be a very safe and attractive investment that could be held directly by cash managers and money-market mutual funds, boosting the supply of STSI. This approach could also help if higher leverage ratio requirements lead dealer firms to engage in a smaller quantity of repo against Treasury securities, which would deprive money funds of a favored short-term investment. Reverse repurchase agreements with the central bank could essentially fill in this demand.

In this regard, the preliminary evidence from the ongoing testing of the Federal Reserve's full-allotment overnight reverse repurchase agreement (ON RRP) facility is especially interesting. Figure 7 shows that there is a negative correlation between Treasury-bill supply and the ON RRP take-up. For example, the figure shows that ON RRP take-up increased significantly around the April 15 tax date, when bill issuance, and hence bills outstanding, was down. This finding suggests that reverse repo agreements with a central bank are very similar to Treasury bills as a form of public supply of STSI and can help meet the demand for STSI and lower the incentives to issue private STSI. It is important to note, however, that increases in reverse repurchase agreements at the central bank reduce reserve balances by an equal amount when central bank assets are unchanged and so do not increase the total supply of STSI. However, the marginal effect of the increases in the reverse repurchase agreements may be higher because of their ability to reach nonbank counterparties who may be more responsive to changes in the money premium compared with banks whose demand for STSI may already be satiated. This is consistent with the evidence that reverse repurchase agreements conducted as part of the ongoing exercises by the Federal Reserve seem to have lessened the relationship between the supply of Treasury collateral and short-term rates.

4.2 Twist Operations

Finally, a central bank could sell short-term Treasury securities and buy longer-term Treasury securities (a so-called twist operation), which would increase the public supply of short-term Treasury securities, which are more STSI-like than long-term Treasury securities. Any such operation could only continue as long as the central bank had shorter-term securities to sell. Therefore, it could only respond to transitory increases in the money premium. The Federal Reserve's sales of shorter-term securities during the Maturity Extension Program (MEP) provide an example of this type of approach and one that contributed to noticeably higher repo rates.[17]

5. Conclusion

Our analysis provides some suggestive evidence in support of the hypothesis that increasing the supply of public STSI reduces the attractiveness of private STSI, and thus potentially helps improve

[17]It is unclear if the elevated repo rates were the direct result of increased supply of STSI or other factors. For example, market participants attributed the higher rates to the primary dealers' inventory of securities expanding to higher-than-desired levels as a result of the MEP. While dealers tended to buy the securities the Federal Reserve was selling and then later find a buyer, the dealers needed to finance the increased holdings of securities in funding markets.

the stability of the financial system. For example, the regression results support the notion that private and public STSI are substitutes, so that greater provision of STSI by a central bank—for example, through reverse repurchase agreements—could meet the demand for STSI and help crowd out creation of private STSI. Nevertheless, as we note, the precise extent to which an increase in public STSI would crowd out private STSI remains uncertain. Given this uncertainty and the potential benefits of public money creation, additional research regarding the money premium, its dynamics and relationship with monetary policy, and the operations of the central bank is warranted.

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Supplementary Appendix

This supplementary appendix contains robustness analysis of the discrete choice models. It contains a review and preview of research using payment diaries. Finally, we provide ancillary tables and figures for the supplementary materials along with an extensive variable list for the macroeconomic and aggregate variables.

Robustness Analysis

This section provides a detailed discussion of the robustness analysis conducted for the paper. We first discuss the unconditional evidence, or the cross-tabs of the proportion of respondents who hold any form of a payment card (either debit or credit). Later, we focus our attention on the conditional analysis via logit models.

Unconditional Evidence

Table A1 provides a table of the proportion of respondents who hold any form of a payment card (either debit or credit). Adding this tighter restriction does not change the proportions significantly, with the exception of the United States, where the rate of card ownership increases. The Dutch numbers are not updated, since debit card ownership is almost universal. For Australia, the results would be similar to Canada.

Conditional Evidence

Tables A2 and A3 summarize the results from the respective robustness test. We have conducted the test for five countries. NL was omitted because card ownership is universal. We could not get the regressions for AU in time; however, the structure of card ownership is very similar to CA. As CA has almost universal card ownership, we expect the results for AU to be very comparable to those from CA.

Specifically, table A2 compares, country by country, the results for the full sample of respondents (as shown in table 9 of the paper) with the results for a sample of respondents who possess either a debit or a credit card. The first result we note is that the sample

Table A1. Card Ownership by Sociodemographics

	AU	AT	CA	FR	DE	NL	US
Debit Card Ownership by Sociodemographics							
Age:							
18–35	0.96	0.95	0.97	0.91	0.96	1.00	0.77
36–60	0.94	0.89	0.98	0.91	0.95	0.99	0.79
60+	0.88	0.69	0.94	0.86	0.91	0.99	0.69
Education:							
Low	0.94	0.79	0.89	0.81	0.86	0.99	0.71
Medium	0.86	0.91	0.98	0.90	0.98	0.99	0.86
High	0.91	0.96	0.97	0.96	0.99	0.99	0.80
Income:							
Low	0.88	0.78	0.96	0.83	0.89	0.98	0.62
Medium	0.95	0.90	0.97	0.93	0.96	0.99	0.82
High	0.94	0.93	0.97	0.96	0.97	0.99	0.82
Any Card Ownership by Sociodemographics							
Age:							
18–35	—	0.95	0.98	0.83	0.96	—	0.79
36–60	—	0.91	0.99	0.92	0.96	—	0.89
60+	—	0.70	1.00	0.97	0.91	—	0.96
Education:							
Low	—	0.80	0.95	0.83	0.87	—	0.82
Medium	—	0.92	0.99	0.92	0.98	—	0.96
High	—	0.97	0.99	0.97	0.99	—	0.98
Income:							
Low	—	0.78	0.99	0.84	0.89	—	0.69
Medium	—	0.91	0.99	0.95	0.96	—	0.94
High	—	0.94	0.99	0.96	0.98	—	0.97

Notes: The top part of the table is taken from table 6 of the main paper. The bottom portion shows calculations based on respondents reporting ownership of either a debit or credit card. AU is similar to CA, while in NL ownership of debit cards is almost universal, so this exercise is omitted.

size is reduced by 9.5 percent in AT, 6.6 percent in DE, 4.5 percent in US, 4.2 percent in FR, and only 0.3 percent in CA (and presumably about the same value in AU). The estimation results reveal only very slight differences between the estimates from the

Table A2. Robustness: Cash versus Non-cash Payment Choice for Full Sample and for Card Owners (marginal effects)

	AT		CA		DE		FR		US	
	Full Sample	**Card=1**	**Full Sample**	**Card=1**	**Full Sample**	**Card=1**	**Full Sample**	**Card=1**	**Full Sample**	**Card=1**
Medium Income	−0.031	−0.020	0.021	0.020	−0.005	−0.006	−0.046**	−0.031	−0.119***	−0.103***
	(0.017)	(0.018)	(0.021)	(0.021)	(0.011)	(0.012)	(0.017)	(0.017)	(−0.020)	(0.021)
High Income	−0.035	−0.022	0.014	0.014	−0.013	−0.013	−0.071*	−0.059	−0.119***	−0.101***
	(0.019)	(0.021)	(0.027)	(0.027)	(0.012)	(0.012)	(0.031)	(0.033)	(−0.025)	(0.026)
Aged 36 to 59	0.071***	0.080***	0.041*	0.044*	0.024*	0.025*	0.051**	0.042*	0.091***	0.101***
	(0.017)	(0.018)	(0.019)	(0.019)	(0.010)	(0.011)	(0.017)	(0.017)	(−0.023)	(0.024)
Aged over 60	0.112***	0.107***	0.026	0.029	0.047**	0.046*	0.042	0.048	0.073*	0.094**
	(0.027)	(0.030)	(0.031)	(0.031)	(0.018)	(0.019)	(0.028)	(0.029)	(−0.029)	(0.030)
Medium Education	−0.040*	−0.033	−0.106**	−0.105**	−0.034***	−0.034**	−0.045*	−0.045	−0.126**	−0.095
	(0.020)	(0.022)	(0.039)	(0.039)	(0.010)	(0.010)	(0.022)	(0.024)	(−0.047)	(0.058)
High Education	−0.080***	−0.068***	−0.134***	−0.132**	−0.085***	−0.085***	−0.097***	−0.089**	−0.194***	−0.167**
	(0.015)	(0.016)	(0.040)	(0.040)	(0.014)	(0.014)	(0.027)	(0.028)	(−0.046)	(0.057)
Not Homeowner	0.012	0.008	0.027	0.030					0.010	0.004
	(0.014)	(0.015)	(0.022)	(0.022)					(−0.021)	(0.022)
Perceptions of: Ease	0.123***	0.107**	0.170***	0.170***					0.212***	0.202***
	(0.037)	(0.041)	(0.045)	(0.046)					(−0.035)	(0.036)
Cost	−0.046	−0.059*	0.082	0.075					0.037	0.040
	(0.025)	(0.026)	(0.043)	(0.043)					(−0.045)	(0.050)
Security	0.082***	0.083***	−0.054**	−0.053**					0.064***	0.061***
	(0.016)	(0.017)	(0.020)	(0.020)					(−0.014)	(0.015)
Acceptance	−0.023	0.031	−0.080	−0.078					0.054	0.029
	(0.042)	(0.047)	(0.045)	(0.045)					(−0.045)	(0.045)
Card Acceptance Share at the POS	−0.104***	−0.110***	−0.480***	−0.483***	−0.105***	−0.095***				
	(0.025)	(0.029)	(0.033)	(0.033)	(0.016)	(0.016)				

(*continued*)

Table A2. (Continued)

	AT		CA		DE		FR		US	
	Full Sample	**Card=1**	**Full Sample**	**Card=1**	**Full Sample**	**Card=1**	**Full Sample**	**Card=1**	**Full Sample**	**Card=1**
Cash on Hand	0.002	0.002	0.005***	0.005***	0.002***	0.002***	0.001***	0.001***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(−0.001)	(0.001)
Gasoline	−0.071***	−0.076***	−0.008	−0.008	−0.098***	−0.099***	−0.161***	−0.167***	0.020	0.011
	(0.014)	(0.016)	(0.028)	(0.028)	(0.007)	(0.007)	(0.027)	(0.030)	(−0.019)	(0.021)
Semi-durables	−0.047***	−0.053***	−0.036*	−0.036*	−0.082***	−0.084***	−0.098***	−0.106***	−0.060**	−0.059**
	(0.012)	(0.013)	(0.017)	(0.018)	(0.008)	(0.008)	(0.016)	(0.016)	(−0.019)	(0.020)
Services	0.080**	0.086**	0.031	0.027	0.048***	0.051***	−0.029*	−0.031*	0.138***	0.144***
	(0.025)	(0.027)	(0.029)	(0.029)	(0.011)	(0.011)	(0.014)	(0.015)	(−0.019)	(0.019)
Entertainment	0.167***	0.179***	0.109***	0.108***	0.081***	0.086***	−0.098***	−0.101***	0.090***	0.102***
	(0.021)	(0.022)	(0.017)	(0.017)	(0.012)	(0.012)	(0.018)	(0.018)	(−0.016)	(0.016)
Other (Not Groceries)	0.075***	0.088***	0.084***	0.084***	0.061***	0.066***	0.040**	0.041**	0.409***	0.427***
	(0.017)	(0.019)	(0.018)	(0.018)	(0.010)	(0.010)	(0.015)	(0.016)	(−0.040)	(0.041)
TV Q2	−0.168***	−0.175***	−0.254***	−0.256***	−0.117***	−0.120***	−0.241***	−0.244***	−0.178***	−0.185***
	(0.022)	(0.023)	(0.016)	(0.016)	(0.021)	(0.021)	(0.035)	(0.036)	(−0.016)	(0.016)
TV Q3	−0.263***	−0.278***	−0.397***	−0.398***	−0.243***	−0.249***	−0.454***	−0.464***	−0.305***	−0.315***
	(0.023)	(0.025)	(0.015)	(0.015)	(0.020)	(0.021)	(0.033)	(0.033)	(−0.015)	(0.015)
TV Q4	−0.364***	−0.393***	−0.549***	−0.549***	−0.373***	−0.380***	−0.629***	−0.643***	−0.462***	−0.472***
	(0.023)	(0.024)	(0.015)	(0.015)	(0.020)	(0.021)	(0.028)	(0.028)	(−0.017)	(0.017)
Observations	7,841	7,095	12,652	12,617	18,676	17,884	7,098	6,631	10,671	10,189

Notes: The dependent variable takes a value of 1 if a payment is made by cash and 0 if it is made by debit or credit. For each country, the first column shows the results for the full sample (as in table 9 of the main paper) and the second column shows the results for the restricted sample, which includes only owners of debit or credit cards. Results for location (urban/rural), marital status, gender, employment status, and family size are not shown. Variables are defined in table 13 in the main paper. TV Q2, TV Q3, and TV Q4 denote the second to fourth quartile of transaction values. Standard errors are in parentheses and the 1, 5, and 10 percent levels of significance are denoted by ***, **, and *, respectively.

Table A3. Robustness Gas and Grocery Transactions: Cash vs. Non-cash Payment Choice at Gas and Groceries for Full Sample and for Card Owners (marginal effects)

	AT		CA		DE		FR		US	
	Full Sample	Card=1	Full Sample	Card=1	Full Sample	Card=1	Full Sample	Card=1	Full Sample	Card=1
Medium Income	−0.025	−0.012	0.042	0.042	−0.009	−0.007	−0.047**	−0.033	−0.133***	−0.119***
	(0.024)	(0.026)	(0.029)	(0.029)	(0.014)	(0.015)	(0.000)	(0.000)	(0.000)	(0.000)
High Income	−0.039	−0.022	0.002	0.002	−0.012	−0.009	−0.073*	−0.062	−0.162***	−0.146***
	(0.029)	(0.031)	(0.037)	(0.037)	(0.015)	(0.015)	(0.000)	(0.000)	(0.000)	(0.000)
Aged 36 to 59	0.086***	0.102***	0.077**	0.077**	0.026	0.027	0.057**	0.049**	0.105***	0.121***
	(0.023)	(0.026)	(0.024)	(0.024)	(0.014)	(0.015)	(0.000)	(0.000)	(0.000)	(0.000)
Aged over 60	0.127***	0.124**	0.080	0.080	0.069**	0.070**	0.043	0.047	0.059	0.093*
	(0.039)	(0.043)	(0.043)	(0.043)	(0.022)	(0.023)	(0.000)	(0.000)	(0.000)	(0.000)
Medium Education	−0.069*	−0.064*	−0.073	−0.073	−0.043***	−0.004***	−0.051*	−0.052*	−0.138*	−0.087
	(0.028)	(0.031)	(0.051)	(0.051)	(0.013)	(0.013)	(0.000)	(0.000)	(0.000)	(0.000)
High Education	−0.102***	−0.088***	−0.123*	−0.124*	−0.118***	−0.120***	−0.106***	−0.099***	−0.210***	−0.164*
	(0.021)	(0.024)	(0.052)	(0.052)	(0.019)	(0.020)	(0.000)	(0.000)	(0.000)	(0.000)
Not Homeowner	0.035	0.033	0.046	0.046					0.053	0.044
	(0.020)	(0.021)	(0.029)	(0.029)					(0.000)	(0.000)
Perceptions of: Ease	0.212***	0.193**	0.161**	0.161**					0.240***	0.227***
	(0.055)	(0.063)	(0.055)	(0.055)					(0.000)	(0.000)
Cost	−0.077*	−0.090*	0.108	0.108					0.000	−0.014
	(0.037)	(0.041)	(0.061)	(0.061)					(0.000)	(0.000)
Security	0.114***	0.121***	−0.055*	−0.055*					0.045*	0.041*
	(0.024)	(0.027)	(0.026)	(0.026)					(0.000)	(0.000)
Acceptance	−0.134*	−0.072	−0.051	−0.051					−0.008	−0.042
	(0.056)	(0.067)	(0.076)	(0.076)					(0.000)	(0.000)
Card Acceptance Share at the POS	−0.178***	−0.178***	−0.561***	−0.560***	−0.080***	−0.065***				
	(0.032)	(0.039)	(0.036)	(0.036)	(0.018)	(0.019)				

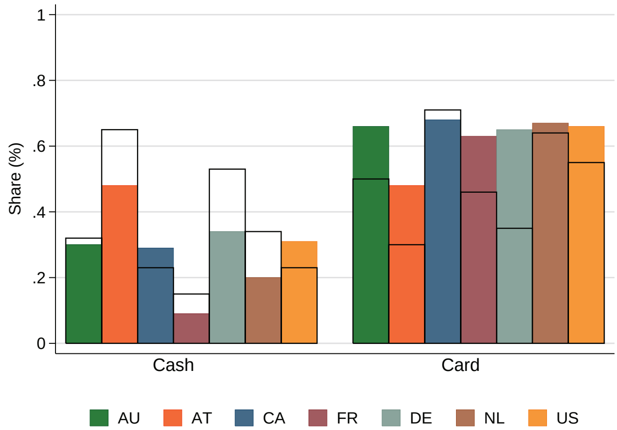
(continued)

Table A3. (Continued)

	AT		CA		DE		FR		US	
	Full Sample	**Card=1**	**Full Sample**	**Card=1**	**Full Sample**	**Card=1**	**Full Sample**	**Card=1**	**Full Sample**	**Card=1**
Cash on Hand	0.003*	0.003	0.006***	0.006***	0.003***	0.003**	0.001***	0.001***	0.002**	0.002**
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Gasoline	−0.088***	−0.096***	−0.011	−0.011	−0.114***	−0.117***	−0.140***	−0.145***	0.024	0.019
	(0.017)	(0.019)	(0.028)	(0.028)	(0.008)	(0.008)	(0.000)	(0.000)	(0.000)	(0.000)
TV Q2	−0.201***	−0.213***	−0.284***	−0.285***	−0.189***	−0.198***	−0.259***	−0.263***	−0.176***	−0.186***
	(0.029)	(0.031)	(0.025)	(0.025)	(0.028)	(0.029)	(0.000)	(0.000)	(0.000)	(0.000)
TV Q3	−0.302***	−0.326***	−0.409***	−0.409***	−0.341***	−0.355***	−0.486***	−0.498***	−0.336***	−0.353***
	(0.030)	(0.033)	(0.023)	(0.023)	(0.028)	(0.029)	(0.000)	(0.000)	(0.000)	(0.000)
TV Q4	−0.420***	−0.464***	−0.572***	−0.573***	−0.481***	−0.499***	−0.666***	−0.684***	−0.466***	−0.481***
	(0.029)	(0.031)	(0.025)	(0.025)	(0.027)	(0.029)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	3,875	3,455	5,079	5,077	10,364	9,839	7,098	6,631	3,688	3,462
Log-Likelihood							−2,546.1	−2,422.9	−75,484.1	−69,920.0

Notes: The dependent variable takes a value of 1 if a payment is made by cash and 0 if it is made by debit or credit. For each country, the first column shows the results for the full sample (as in table 9 of the main paper) and the second column shows the results for the restricted sample, which includes only owners of debit or credit cards. Results for location (urban/rural), marital status, gender, employment status, and family size are not shown. Variables are defined in table 13 in the paper. TV Q2, TV Q3, and TV Q4 denote the second to fourth quartile of transaction values. Standard errors are in parentheses and the 1, 5, and 10 percent levels of significance are denoted by ***, **, and *, respectively.

Figure A1. Cash and Card (Debit and Credit) Share for Purchases at Gas Stations



Note: The transparent bars show the overall cash and card shares, the colored bars the respective shares at gas stations.

unrestricted sample and the estimates from the restricted sample. Notably, this also holds for AT and DE with the largest drop in the number of observations. If at all, differences arise, expectedly, for the sociodemographic variables, e.g., income for FR and education for US. Importantly, the estimates for "Cash on Hand" is not affected by the sample restriction. In other words, "Cash on Hand" does not act as a proxy for payment cardholding. Qualitatively, the same findings apply if we analyze only gas station and grocery transactions (table A3; see also figure A1).

Given these results, we have added a description of the robustness test and its core findings in the paper.

Payment Diaries: Past and Present

The usage of consumer payment diaries to understand monetary and payment economics is in the nascent stage. This section provides a brief summary of how payment diaries have been used to understand (i) cash usage, (ii) determinants of payment instrument choice, and (iii) how market structure may matter for payment choice.

Consumer Cash Usage

A key advantage of payment diaries is the proper accounting of cash payments relative to all methods of payment. Stix (2004) and Bounie, Francois, and Waelbroeck (2013) demonstrate that cash demand is affected by debit card usage for AU and FR, respectively. For DE, credit cards are relatively interchangeable with debit cards for the usage of cash; see von Kalckreuth, Schmidt, and Stix (2014a). Further work by von Kalckreuth, Schmidt, and Stix (2014b) uses payment diary data for DE to show that cash is used as a method to monitor expenditures (*pocket-watching*). Fung, Huynh, and Sabetti (2012) investigate the effect of retail payment innovations (i.e., contactless credit cards and stored-value cards) on cash usage and find that there is a reduction. Finally, Bounie, Francois, and Waelbroeck (2013) and Huynh, Schmidt-Dengler, and Stix (2014) study the impact of card acceptance on cash usage. They find that the lack of card acceptance is a reason for precautionary cash balances.

Consumer Adoption and Use of Payment Instruments

The study by Bounie and Francois (2006), based on a 2005 French payment diary, was an early attempt to disentangle the effect of demographics from the effect of payment characteristics such as transaction value on payment choice. Further work by Bouhdaoui and Bounie (2012) proposes a cash holding model as an alternative to a transaction-size explanation for payment choice.[1] Kosse and Jansen (2013) demonstrate that a variation in demographics such as foreign background has a strong effect on payment choice for NL.

Simon, Smith, and West (2010) (for AU); Arango, Huynh, and Sabetti (2011) (for CA); and Wakamori and Welte (2012) (for CA) extend the analysis beyond demographics and payment characteristics to pricing incentives such as card affinity programs (rewards) and acceptance of payment cards. The analysis by Briglevics and Schuh (2013) estimates a structural inventory model of cash holdings and finds a significant effect on payment choice.

[1] Arango et al. (2013) extend this work by conducting the test for CA, FR, DE, and NL.

Merchant Steering

The payment diaries have been used to study the effect of market structure on payment choice. Recent work by Shy (2014) investigates the effect of the debit card interchange fees and sorts out the transaction value at which interchange fees become higher or lower due to the new rule. Briglevics and Shy (2012) use the payment diaries to understand merchant steering. They compute the expected net cost of discounts on cash and debit card payments and find that, for the most part, steering is unprofitable. Welte (2014) studies and extends the steering exercise by embedding a consumer choice into the expected net cost calculations for CA.

Scanner Data Projects

Scanner data have been touted as an alternative to payment diaries as a method of data collection on payments. For US, Klee (2008) uses data to show that payment choice is a function of the amount of time spent processing the items purchased. Research by Polasik et al. (2012) for Poland demonstrates the usage of chronometric methods to enumerate the processing time of payments. Recent work by Wang and Wolman (2014) extends the work of Klee (2008) by using scanner data from a large discount retailer.

These scanner data studies provide rich detailed information, including the opportunity cost of time. One drawback of these scanner data projects is that direct demographic data are not collected. Therefore, it is hard to infer the role of consumer demographics on payment choice. Recent work by Cohen and Rysman (2013) avoids this criticism by obtaining demographic information with the scanner data.

Payment Diaries: Going Forward

This section describes possible future use of payment diaries. We focus on three main points: structural models of cash and alternative means of payment, high-frequency consumption/savings, and the study of two-sided markets. We also discuss some caveats and ideas to improve the collection of data.

Structural Models of Cash and Alternative Method of Payments

The estimation of money demand has relied mostly on the workhorse Baumol-Tobin model. However, this model was constructed in the absence of payment cards. The presence of payment cards has been exploited to understand household money demand elasticities; see Mulligan and Sala-i-Martin (2000) or Attanasio, Guiso, and Jappelli (2002). These studies also document that consumers do not wait until there is a zero cash balance before withdrawing. This inspired Alvarez and Lippi (2009), who explain this puzzle by introducing a positive probability of a *free withdrawal.* Another salient feature is that some consumers hold large amounts of cash. Alvarez and Lippi (2013b) rationalize this feature by modeling the large and lumpy purchases that require cash. Further, Alvarez and Lippi (2013a) allow merchant non-acceptance of cards as a reason to hold precautionary cash balances.

Most payment diaries contain information about cash management behavior, but little is known about the rationale for such holdings. Most diaries do not include questions on precautionary motives or the need to make lumpy purchases. Therefore, it is hard to distinguish between cash management and acceptance of payment cards as a reason to hold cash. Further, care must be taken to conduct the statistical sampling behind these questions. The diaries rely on a short-term window to focus on behavior that may be infrequent.

Nosal and Rocheteau (2012) offer an extensive discussion of the new monetarist approach, which has stressed various real trading frictions to explain the coexistence of cash with cards. For example, Telyukova and Wright (2008) explain why households hold cash while having a credit balance with a rate-of-return dominance puzzle; i.e., cash is held for liquidity reasons to settle claims. The current payment diaries focus mainly on payment choice and expenditures. There is scant information about credit arrangements, i.e., an indicator of whether or not a household has carried a balance from month to month. Therefore, to empirically validate these models would require detailed household balance sheet information.

High-Frequency Consumption and Saving

Recent work by Aruoba, Diebold, and Scotti (2009) highlights the usefulness of real-time monitoring of consumption for business cycles. Private and public sector forecasters spend enormous resources to understand consumption, as it is a large component of GDP. Galbraith and Tkacz (2013) demonstrate the utility of using network data on debit and credit card payments to understand consumption. The recent financial crisis has highlighted the need to understand high-frequency movements in consumption and consumer confidence; see Lachowska (2013) and Parker et al. (2013).

Payment diaries could be a useful method to track the high-frequency consumption and/or expenditures of households. They could be used to understand the effect of fiscal policy on consumption. Agarwal and McGranahan (2012) argue that sales tax holidays have an effect on consumption but the timing of these effects cannot be clearly identified. Also, Mastrobuoni and Weinberg (2010) demonstrate that exact pay dates have an impact on consumption, especially for social security recipients. Payment diaries would need to be redesigned to incorporate questions to determine these effects.

Two-Sided Markets and Regulation

Rochet and Tirole (2002) and Wright (2003) discuss the theoretical nature of two-sided markets for the payments literature. The work on estimating these two-sided markets, with the exception of Rysman (2007), uses network data to study the usage of credit cards, network externalities, and multi-homing. Also, recent work by Shy and Wang (2011) discusses why interchange fees are proportional.

Payment diaries contain detailed data on consumer payments but only a few questions on merchant characteristics (i.e., venue and acceptance of cards). Recent work by Bounie, Francois, and Hove (2014) matches payment diary data to a nationwide French merchant survey to investigate the probability that the merchant will accept cards. Future payment diaries could attempt to collect or at least link their data to merchant costs, or expand the supply-side information. However, work by Stavins and Shy (2015) illustrates the difficulty of this task, as they attempt to embed questions about merchant steering into US payment diaries. Their results are inconclusive, and they discuss the challenges and pitfalls of this exercise. Future attempts to improve payment diaries should bear this in mind.

Macroeconomic and Aggregate Variables: Definitions

Table A4. Definition of Macro Variables

Australia	
Core Inflation	Haver Analytics, Series C193CZCY@OECDMEI (Australia: CPI: All Items excl. Food and Energy (NSA, Year/Year % Change)).
Output Gap	OECD Economic Outlook, Vol. 2014, Issue 1. Annex Table 10.
GDP Growth	Haver Analytics, Series C193GPCY@OECDMEI (Australia: Real GDP: Growth Rate Prev. Year (SA, %)).
Unemployment	Haver Analytics, Series C193LRCL@OECDMEI (Australia: Harmonized Unemployment Rate: All Persons All Ages (SA, %))
NAIRU	Data Set: Economic Outlook No. 95, May 2014, OECD Annual Projections. NAIRU — Unemployment rate with non-accelerating inflation rate.
Currency in Circulation	International Financial Statistics, Series 193"14A____K"J (CURRENCY IN CIRCULATION Millions of). The series starts only in 2001. Older values were constructed using growth rates of 193"14A"J (CURRENCY OUTSIDE BANKS Millions).
Nominal GDP	International Financial Statistics, Series 193"99B_C"J.
Austria	
Core Inflation	Haver Analytics, Series C122CZCY@OECDMEI (Austria: CPI: All Items excl. Food and Energy (NSA, Year/Year % Change)).
Output Gap	OECD Economic Outlook, Vol. 2014, Issue 1. Annex Table 10.
GDP Growth	Haver Analytics, Series C122GPCY@OECDMEI (Austria: Real GDP: Growth Rate Prev. Year (SA, %)).
Unemployment	Haver Analytics, Series C122LRCL@OECDMEI (Austria: Harmonized Unemployment Rate: All Persons All Ages (SA, %)).
NAIRU	Data Set: Economic Outlook No. 95, May 2014, OECD Annual Projections. NAIRU — Unemployment rate with non-accelerating inflation rate.
Currency in Circulation	International Financial Statistics, Series 122"34A_N"J.
Nominal GDP	International Financial Statistics, Series 122"99B"J.

(*continued*)

Table A4. (Continued)

Canada	
Core Inflation	Haver Analytics, Series C156CZCY@OECDMEI (Canada: CPI: All Items excl. Food and Energy (NSA, Year/Year % Change)).
Output Gap	OECD Economic Outlook, Vol. 2014, Issue 1. Annex Table 10.
GDP Growth	Haver Analytics, Series C156GPCY@OECDMEI (Canada: Real GDP: Growth Rate Prev. Year (SA, %)).
Unemployment	Haver Analytics, Series C156LRCL@OECDMEI (Canada: Harmonized Unemployment Rate: All Persons All Ages (SA, %))
NAIRU	Data Set: Economic Outlook No. 95, May 2014, OECD Annual Projections. NAIRU — Unemployment rate with non-accelerating inflation rate.
Currency in Circulation	Haver Analytics, Series S156FMC@G10 (Money Supply: Currency in Circulation (Avg./Weds, SA, Mil.C$)).
Nominal GDP	International Financial Statistics, Series 156"99BAC"J.
France	
Core Inflation	Haver Analytics, Series C132CZCY@OECDMEI (France: CPI: All Items excl. Food and Energy (NSA, Year/Year % Change)).
Output Gap	OECD Economic Outlook, Vol. 2014, Issue 1. Annex Table 10.
GDP Growth	Economics: Key tables from OECD — ISSN 2074-384x. Quarterly gross domestic product, change over same quarter, previous year.
Unemployment	Haver Analytics, Series C132LRCL@OECDMEI (France: Harmonized Unemployment Rate: All Persons All Ages (SA, %)).
NAIRU	Data Set: Economic Outlook No. 95, May 2014, OECD Annual Projections. NAIRU — Unemployment rate with non-accelerating inflation rate.
Currency in Circulation	International Financial Statistics, Series 132"14A"J.
Nominal GDP	International Financial Statistics, Series 132"99B_C" and 132"99B_C.

(*continued*)

Table A4. (Continued)

Germany	
Core Inflation	Haver Analytics, Series C134CZCY@OECDMEI (Germany: CPI: All Items excl. Food and Energy (NSA, Year/Year % Change)).
Output Gap	OECD Economic Outlook, Vol. 2014, Issue 1. Annex Table 10.
GDP Growth	Haver Analytics, Series C134GPCY@OECDMEI (Germany: Real GDP: Growth Rate Prev. Year (SA, %)).
Unemployment	Haver Analytics, Series C134LRCL@OECDMEI (Germany: Harmonized Unemployment Rate: All Persons All Ages (SA, %)).
NAIRU	Data Set: Economic Outlook No. 95, May 2014, OECD Annual Projections. NAIRU — Unemployment rate with non-accelerating inflation rate.
Currency in Circulation	Deutsche Bundesbank — Circulation of Currency emitted in Germany, bill euro ("Umlauf von in Deutschlandemittiertem Bargeld, Mrd. Euro").
Nominal GDP	International Financial Statistics, Series 134"99B_C (Bil DEM) and 134"99B_C___W"J (Bil Euro).
Netherlands	
Core Inflation	Haver Analytics, Series C138CZCY@OECDMEI (Netherlands: CPI: All Items excl. Food and Energy (NSA, Year/Year % Change)).
Output Gap	OECD Economic Outlook, Vol. 2014, Issue 1. Annex Table 10.
GDP Growth	Haver Analytics, Series C138GPCY@OECDMEI (Netherlands: Real GDP: Growth Rate Prev. Year (SA, %)).
Unemployment	Haver Analytics, Series C138LRCL@OECDMEI (Netherlands: Harmonized Unemployment Rate: All Persons All Ages (SA, %)).
NAIRU	Data Set: Economic Outlook No. 95, May 2014, OECD Annual Projections. NAIRU — Unemployment rate with non-accelerating inflation rate.
Currency in Circulation	International Financial Statistics, Series 138"14A"J.
Nominal GDP	International Financial Statistics, Series 138"99B_C" and 138"99B_C.

(*continued*)

Table A4. (Continued)

United States	
Core Inflation	Haver Analytics, Series C111CZCY@OECDMEI (United States: CPI: All Items excl. Food and Energy (NSA, Year/Year % Change)).
Output Gap	OECD Economic Outlook, Vol. 2014, Issue 1. Annex Table 10.
GDP Growth	Haver Analytics, Series C111GPCY@OECDMEI (United States: Real GDP: Growth Rate Prev. Year (SA, %)).
Unemployment	Haver Analytics, Series C111LRCL@OECDMEI (United States: Harmonized Unemployment Rate: All Persons All Ages (SA, %)).
NAIRU	Data Set: Economic Outlook No. 95, May 2014, OECD Annual Projections. NAIRU — Unemployment rate with non-accelerating inflation rate.
Total Currency in Circulation	Federal Reserve Board, "H.6 Money Stock Measures — Table 3," http://www.federalreserve.gov/releases/h6/current/default.htm#t3tglfl.
Foreign Currency in Circulation	Federal Reserve Board, "L.204 Checkable Deposits and Currency — Line 25 (Series FL263025003.Q)." (Note that the domestic currency in circulation is found by subtracting the foreign currency in circulation from the total currency in circulation.) http://www.federalreserve.gov/apps/fof/SeriesAnalyzer.aspx?s=FL263025003&t=L.204&suf.
Nominal GDP	U.S. Bureau of Economic Analysis, Table 1.1.5. Gross Domestic Product, http://bea.gov/iTable/iTable.cfm?ReqID=9&step=1#reqid=9&step=3&isuri=1&903=5.
Euro Area	
Currency in Circulation	ECB Statistical Data Warehouse (http://sdw.ecb.europa.eu/), Series BSI.M.U2.N.C.L10.X.1.Z5.0000.Z01.E. Euro area (changing composition), Outstanding amounts at the end of the period (stocks), Eurosystem reporting sector — Currency in circulation, All currencies combined — World not allocated (geographically) counterpart, Unspecified counterpart sector, denominated in euro, data neither seasonally nor working-day adjusted. This series is only available

(*continued*)

Table A4. (Continued)

Euro Area	
	back until 1997. Values from 1980 to 1996 were constructed using annual growth rates of series BSI.M.U2.Y.V.L10.X.1.U2.2300.Z01.E (euro area (changing composition), outstanding amounts at the end of the period (stocks), MFIs, central government and post office giro institutions reporting sector — currency in circulation).
Nominal GDP	New Cronos Database, Gross Domestic Product at Market Prices, Euro Area in changing composition (EA11-2000, EA12-2006, EA13-2007, EA15-2008, EA16-2010, EA17-2013, EA18) Series NAMQ_GDP_C.S_ADJ.SWDA.UNIT.MIO_EUR. INDIC_NA.B1GM.GEO.EA. This nominal GDP construction used growth rates from a nominal GDP series from the ECB area-wide model. See annex 2 in Fagan, Henry, and Mestre (2005).

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Fedspeak: Who Moves U.S. Asset Prices?
Online Appendix

Carlo Rosa

Federal Reserve Bank of New York

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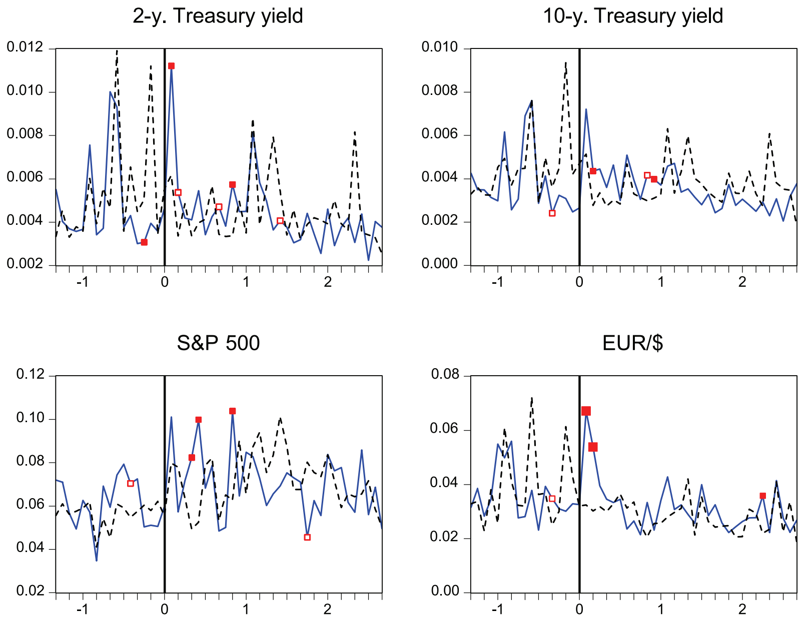
Appendix A. Additional Results

Figure A1. The Volatility of Asset Prices around Chairman Bernanke's Speeches: Subsamples

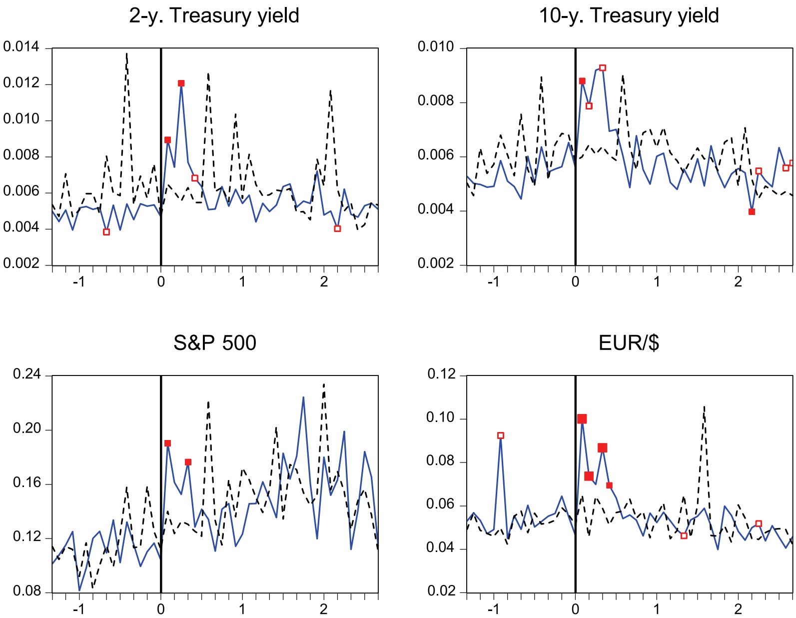
A. Sample: February 2006–December 2007



(continued)

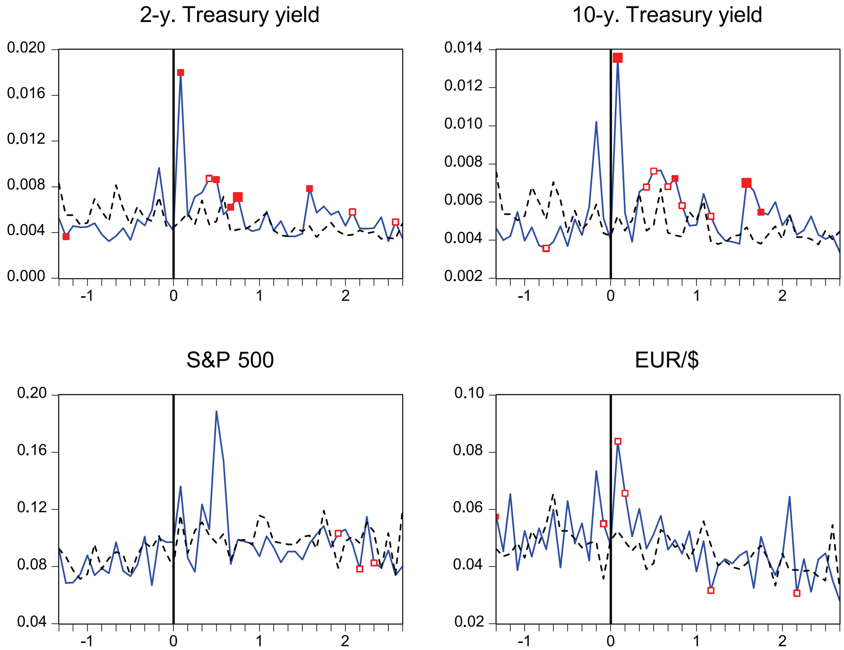
Figure A1. (Continued)

B. Sample: January 2008–December 2012



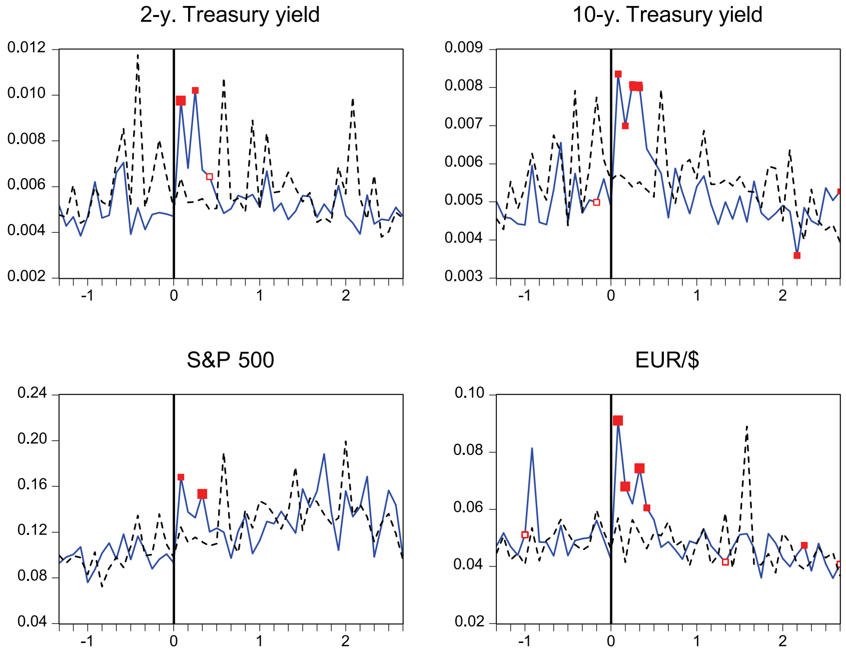
Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the speeches of Federal Reserve Chairman Bernanke with a solid blue line and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line for two different samples: February 2006–December 2007 in panel A and January 2008–December 2012 in panel B. Returns are five-minute yield changes for Treasury rates and five-minute percentage changes for the S&P 500 and the euro–dollar exchange rate. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure A2. The Volatility of Asset Prices around Chairman Greenspan's Speeches



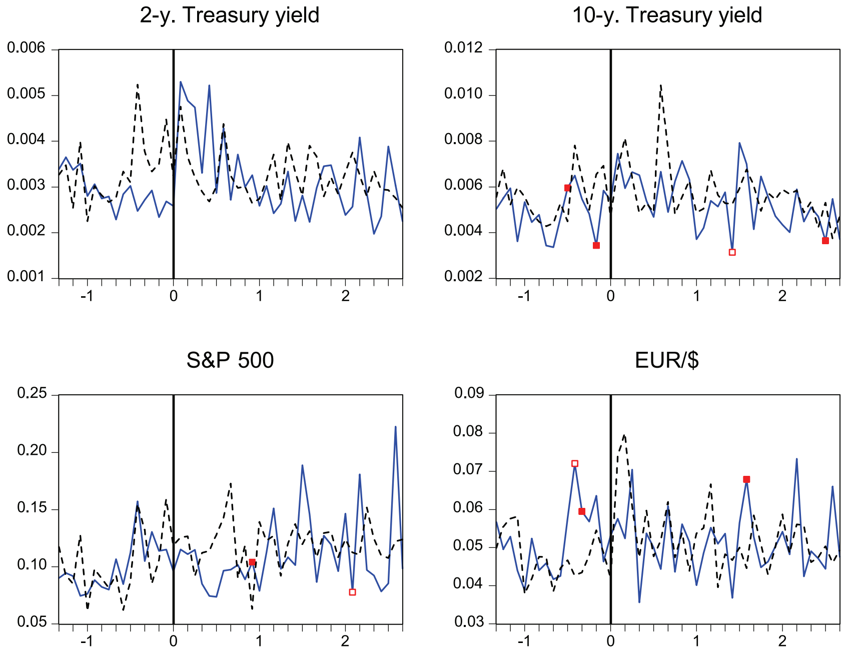
Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the speeches of Federal Reserve Chairman Greenspan with a solid blue line and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 2001–January 31, 2006. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure A3. The Volatility of Asset Prices around Chairman Bernanke's Speeches



Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the speeches of Federal Reserve Chairman Bernanke with a solid blue line and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is February 1, 2006–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

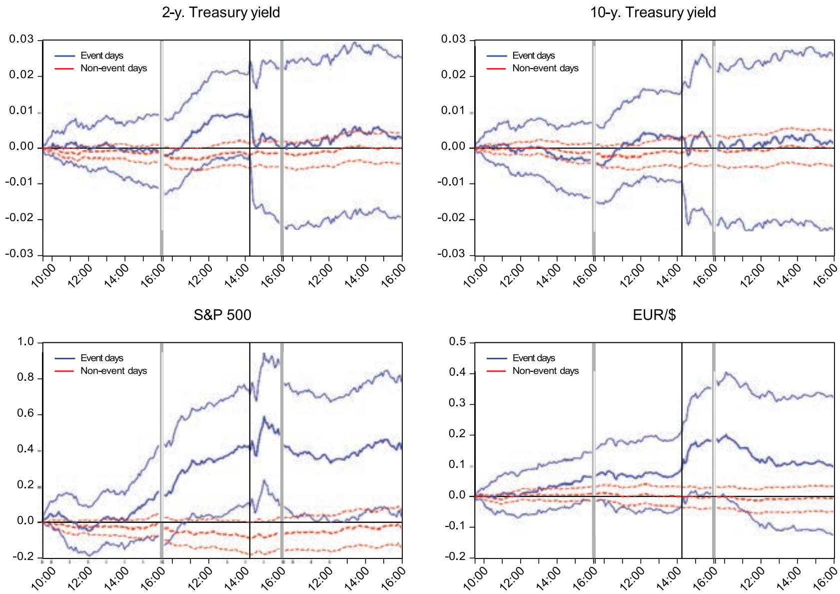
Figure A4. The Volatility of Asset Prices around FRBNY President Dudley's Speeches



Notes: This figure plots (i) the standard deviation of five-minute asset price returns around the release time of the speeches of Federal Reserve Bank of New York President Dudley with a solid blue line and (ii) the standard deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 27, 2009–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. Brown and Forsythe (1974) statistics are employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

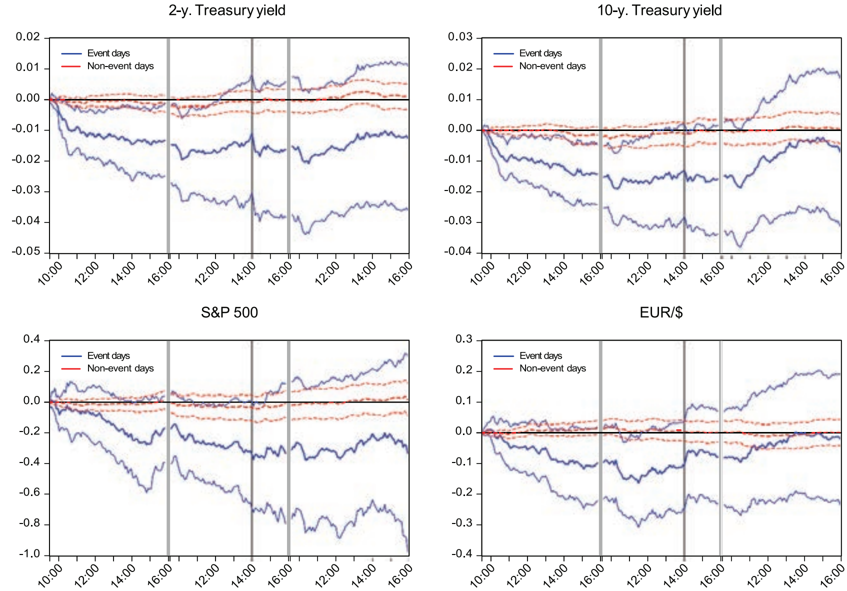
Appendix B. Pre-event Drift

Figure B1. Cumulative Asset Price Returns: FOMC Statement



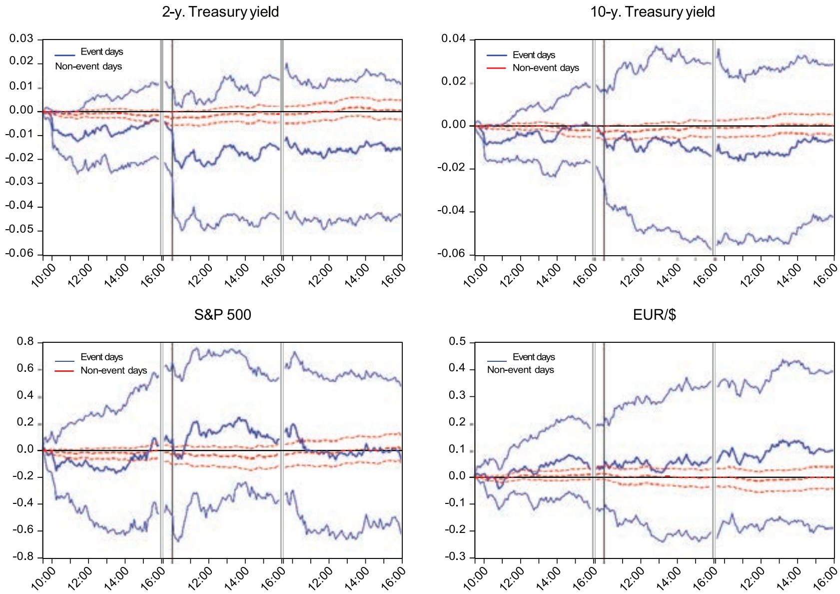
Notes: The figure displays the average cumulative returns on selected asset-prices on three-day windows. The five-minute asset return is the five-minute yield changes for the fixed-income instruments and the five-minute percentage changes for stock prices and the euro–dollar exchange rate. The five-minute returns are centered at zero. The sample period is from January 2001 to March 2011, and it includes only scheduled FOMC meetings. The thick solid blue line is the average cumulative return from 9:30 a.m. ET on days before to 4 p.m. ET on days after scheduled FOMC announcements. The thick red dashed line shows average cumulative returns on all other three-day windows that do not include FOMC announcements. The gray shaded areas are the end of the trading day. The thin lines represent 95 percent confidence bands around the average cumulative returns. The black vertical line is set at 2:15 p.m. ET, when FOMC statements are typically released in this sample period.

Figure B2. Cumulative Asset Price Returns: FOMC Minutes



Notes: The figure displays the average cumulative returns on selected asset prices on three-day windows. The five-minute asset return is the five-minute yield changes for the fixed-income instruments and the five-minute percentage changes for stock prices and the euro–dollar exchange rate. The five-minute returns are centered at zero. The sample period is from January 2005 to April 2011 (see Rosa 2013 for the choice of this sample). The thick solid blue line is the average cumulative return from 9:30 a.m. ET on days before to 4 p.m. ET on days after the FOMC minutes releases. The thick red dashed line shows average cumulative returns on all other three-day windows that do not include FOMC minutes releases. The gray shaded areas are the end of the trading day. The thin lines represent 95 percent confidence bands around the average cumulative returns. The black vertical line is set at 2 p.m. ET, when FOMC minutes are typically released in this sample period.

Figure B3. Cumulative Asset Price Returns: Monetary Policy Report



Notes: The figure displays the average cumulative returns on selected asset prices on three-day windows. The five-minute asset return is the five-minute yield changes for the fixed-income instruments and the five-minute percentage changes for stock prices and the euro–dollar exchange rate. The five-minute returns are centered at zero. The sample period is from January 2001 to December 2012. The thick solid blue line is the average cumulative return from 9:30 a.m. ET on days before to 4 p.m. ET on days after the release of the Monetary Policy Report. The thick red dashed line shows average cumulative returns on all other three-day windows that do not include FOMC minutes releases. The gray shaded areas are the end of the trading day. The thin lines represent 95 percent confidence bands around the average cumulative returns. The black vertical line is set at 10 a.m. ET, when the Monetary Policy Reports are typically released in this sample period.

Figure B4. Distribution of Announcement Times of Federal Reserve Events

A. Scheduled Releases (FOMC Statement, FOMC Minutes, and Monetary Policy Report)

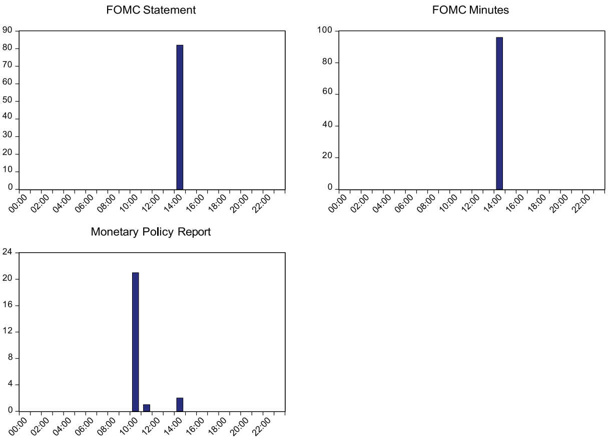


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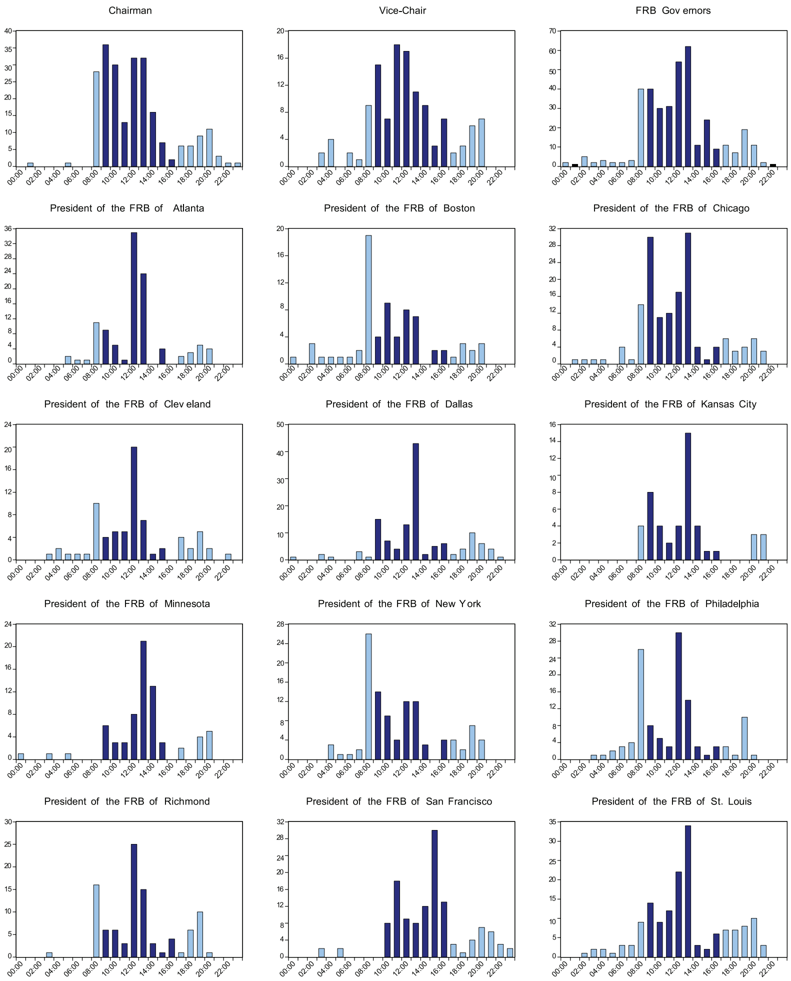
Figure B4. (Continued)

B. Speeches by Chairman, Vice Chairman, FRB Governors, and Regional Federal Reserve Bank Presidents



Notes: The figure shows the distribution of announcement times stated in U.S. Eastern Time. Panel A displays scheduled releases, whereas panel B displays the distribution of announcement times of speeches. The sample for FOMC statement is January 2001–March 2001. The sample for FOMC minutes is January 2005–April 2011. The sample for the other types of communication is January 2001–December 2012. Note that one Monetary Policy Report was released at 11 a.m. ET (on February 11, 2004) and two Reports were released in the afternoon (on July 20, 2004 at 2:30 p.m. and on July 21, 2010 at 2 p.m. ET). Dark blue indicates hours between 9 a.m. ET and 4 p.m. ET (standard trading hours), whereas light blue indicates hours before 9 a.m. or after 5 p.m. ET.

Table B1. Daily Returns and the Pre-FOMC Announcement Drift: Scheduled Events

	Two-Year Treasury	Ten-Year Treasury	S&P 500	EUR/$
A. FOMC Statement				
Constant	−0.23	−0.10	−0.02	0.01
	(0.17)	(0.14)	(0.03)	(0.01)
Dummy	0.83	−0.14	0.49***	0.15**
	(0.70)	(0.60)	(0.16)	(0.07)
Adjusted R^2	−0.000	−0.000	0.005	0.001
Observations	1,572	2,114	2,281	2,883
Number of Events	63	74	81	82
B. FOMC Minutes				
Constant	−0.13	−0.10	0.00	0.02
	(0.17)	(0.14)	(0.03)	(0.01)
Dummy	0.85	0.13	−0.05	−0.02
	(0.77)	(0.81)	(0.11)	(0.09)
Adjusted R^2	−0.000	−0.000	−0.000	−0.000
Observations	1,572	2,116	2,282	2,851
Number of Events	34	42	47	51
C. Monetary Policy Report				
Constant	−0.26*	−0.24*	−0.01	0.02
	(0.16)	(0.14)	(0.03)	(0.01)
Dummy	−1.31	−0.01	0.10	0.22
	(1.97)	(1.33)	(0.23)	(0.13)
Adjusted R^2	−0.000	−0.000	−0.000	0.001
Observations	1,691	2,135	2,364	2,513
Number of Events	15	19	21	21

Notes: The table reports the results from a regression of the daily return on a constant term and a dummy variable, which is equal to one on Federal Reserve event dates and zero on all other days. The asset return is yield changes for the fixed-income instruments and the percentage changes for stock prices and the euro–dollar exchange rate. The daily returns are based on intraday data, and by construction, the return ends fifteen minutes before the Federal Reserve announcement has been released. The sample period is from January 2001 to March 2011 for the FOMC statement (panel A), from January 2005 to April 2011 for the FOMC minutes (panel B), and from January 2001 to December 2012 for the Monetary Policy Report (panel C, considering only Monetary Policy Reports released at 10 a.m. ET). The econometric method is ordinary least squares with heteroskedasticity and autocorrelation-consistent standard errors in parentheses. ***, **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively.

Table B2. Daily Returns and the Pre-Federal Reserve Speeches Announcement Drift: Speeches

	Two-Year Treasury	Ten-Year Treasury	S&P 500	EUR/$
A. Chairman				
Constant	−0.23	−0.13	0.00	0.01
	(0.19)	(0.16)	(0.03)	(0.01)
Dummy	0.37	0.40	0.16	−0.09*
	(0.55)	(0.48)	(0.12)	(0.05)
Adjusted R^2	−0.001	−0.000	0.001	0.001
Observations	1,299	1,837	2,184	2,457
Number of Events	200	200	200	200
B. Vice Chair of the Federal Reserve System				
Constant	−0.18	−0.24	0.01	0.02
	(0.19)	(0.16)	(0.03)	(0.01)
Dummy	−0.06	0.75	0.24**	−0.01
	(0.81)	(0.82)	(0.12)	(0.06)
Adjusted R^2	−0.001	−0.000	0.001	−0.000
Observations	1,316	1,754	2,112	2,519
Number of Events	96	96	96	96
C. Governors of the Federal Reserve Board				
Constant	−0.43**	−0.25	0.01	0.01
	(0.20)	(0.16)	(0.03)	(0.01)
Dummy	0.45	0.01	0.05	0.06*
	(0.50)	(0.45)	(0.07)	(0.03)
Adjusted R^2	−0.000	−0.001	−0.000	0.000
Observations	1,381	1,865	2,212	2,537
Number of Events	309	309	309	309
D. President of the Federal Reserve Bank of Atlanta				
Constant	−0.18	−0.23	−0.03	0.01
	(0.18)	(0.15)	(0.03)	(0.01)
Dummy	−0.83	1.06	0.35**	0.07
	(0.79)	(0.81)	(0.17)	(0.08)
Adjusted R^2	−0.000	0.000	0.002	−0.000
Observations	1,406	1,857	2,070	2,388
Number of Events	89	89	89	89

(*continued*)

Table B2. (Continued)

	Two-Year Treasury	**Ten-Year Treasury**	**S&P 500**	**EUR/$**
E. President of the Federal Reserve Bank of Boston				
Constant	−0.22	−0.12	0.02	0.01
	(0.19)	(0.15)	(0.02)	(0.01)
Dummy	−0.55	−0.68	−0.20	0.03
	(1.73)	(1.00)	(0.21)	(0.08)
Adjusted R^2	−0.001	−0.000	0.000	−0.000
Observations	1,193	1,668	2,026	2,352
Number of Events	56	56	56	56
F. President of the Federal Reserve Bank of Chicago				
Constant	−0.26	−0.22	−0.04	0.02
	(0.18)	(0.16)	(0.03)	(0.01)
Dummy	1.15	0.20	0.03	−0.05
	(1.18)	(0.77)	(0.15)	(0.06)
Adjusted R^2	0.001	−0.001	−0.000	−0.000
Observations	1,355	1,739	1,919	2,231
Number of Events	125	125	125	125
G. President of the Federal Reserve Bank of Cleveland				
Constant	−0.53***	−0.37**	0.03	0.03**
	(0.18)	(0.16)	(0.03)	(0.01)
Dummy	0.99	−0.08	−0.11	−0.09
	(0.90)	(0.76)	(0.15)	(0.08)
Adjusted R^2	−0.000	−0.001	−0.000	−0.000
Observations	1,145	1,579	1,932	2,232
Number of Events	56	56	56	56
H. President of the Federal Reserve Bank of Dallas				
Constant	−0.24	−0.26	0.03	0.01
	(0.19)	(0.16)	(0.03)	(0.01)
Dummy	0.74	1.65***	0.10	0.10
	(0.87)	(0.62)	(0.14)	(0.07)
Adjusted R^2	−0.000	0.002	−0.000	0.001
Observations	1,198	1,689	1,947	2,412
Number of Events	97	97	97	97

(*continued*)

Table B2. (Continued)

	Two-Year Treasury	Ten-Year Treasury	S&P 500	EUR/$
I. President of the Federal Reserve Bank of Kansas City				
Constant	−0.24	−0.25*	−0.02	0.01
	(0.20)	(0.15)	(0.03)	(0.01)
Dummy	0.89	0.39	0.25	−0.11
	(0.99)	(0.95)	(0.30)	(0.13)
Adjusted R^2	−0.001	−0.000	0.000	−0.000
Observations	1,298	1,868	2,220	2,565
Number of Events	43	43	43	43
J. President of the Federal Reserve Bank of Minneapolis				
Constant	−0.17	−0.15	−0.00	0.01
	(0.18)	(0.16)	(0.03)	(0.01)
Dummy	−0.58	−0.68	0.01	−0.10
	(1.18)	(0.82)	(0.24)	(0.10)
Adjusted R^2	−0.001	−0.000	−0.001	0.000
Observations	1,357	1,723	1,791	2,056
Number of Events	58	58	58	58
K. President of the Federal Reserve Bank of New York				
Constant	−0.34*	−0.27*	0.00	0.02
	(0.18)	(0.16)	(0.03)	(0.01)
Dummy	0.45	0.40	−0.11	−0.10
	(0.86)	(0.69)	(0.14)	(0.07)
Adjusted R^2	−0.001	−0.000	−0.000	0.000
Observations	1,313	1,822	2,188	2,412
Number of Events	86	86	86	86
L. President of the Federal Reserve Bank of Philadelphia				
Constant	−0.30	−0.11	0.02	0.02*
	(0.19)	(0.16)	(0.03)	(0.01)
Dummy	0.50	0.09	0.16	0.03
	(1.00)	(0.68)	(0.14)	(0.07)
Adjusted R^2	−0.001	−0.001	0.000	−0.000
Observations	1,144	1,541	1,937	2,277
Number of Events	94	94	94	94

(*continued*)

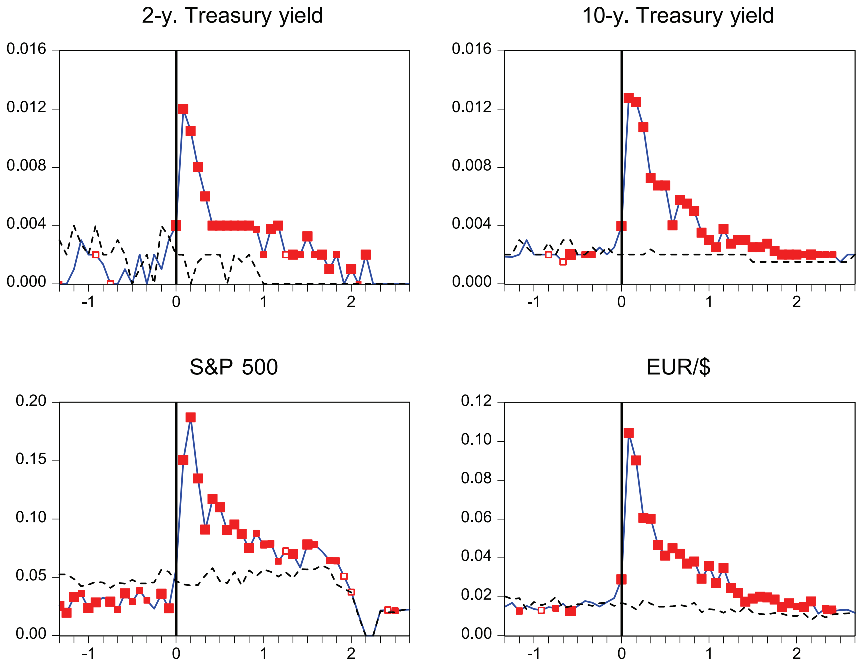
Table B2. (Continued)

	Two-Year Treasury	Ten-Year Treasury	S&P 500	EUR/$
M. President of the Federal Reserve Bank of Richmond				
Constant	−0.25	−0.14	0.01	0.02
	(0.18)	(0.15)	(0.03)	(0.01)
Dummy	−2.26***	−1.37**	−0.24*	−0.10
	(0.76)	(0.69)	(0.13)	(0.08)
Adjusted R^2	0.004	0.001	0.001	0.000
Observations	1,350	1,777	2,039	2,408
Number of Events	80	80	80	80
N. President of the Federal Reserve Bank of San Francisco				
Constant	−0.33	−0.35*	0.01	0.01
	(0.22)	(0.18)	(0.03)	(0.01)
Dummy	1.24	1.30*	−0.00	0.00
	(1.13)	(0.77)	(0.16)	(0.07)
Adjusted R^2	0.000	0.001	−0.001	−0.001
Observations	1,069	1,369	1,500	1,957
Number of Events	98	98	98	98
O. President of the Federal Reserve Bank of St. Louis				
Constant	0.02	0.03	0.03	0.01
	(0.19)	(0.16)	(0.03)	(0.01)
Dummy	−0.87	−0.68	0.02	−0.07
	(0.65)	(0.57)	(0.12)	(0.07)
Adjusted R^2	0.000	−0.000	−0.000	0.000
Observations	1,243	1,669	1,978	2,341
Number of Events	115	115	115	115

Notes: The table reports the results from a regression of the daily return on a constant term and a dummy variable, which is equal to one on Federal Reserve event dates and zero on all other days. The asset return is yield changes for the fixed-income instruments and the percentage changes for stock prices and the euro–dollar exchange rate. The daily returns are based on intraday data, and by construction, the return ends fifteen minutes before the Federal Reserve announcement has been released. The sample period is from January 2001 to March 2011 for the FOMC statement (panel A), from January 2005 to April 2011 for the FOMC minutes (panel B), and from January 2001 to December 2012 for the Monetary Policy Report (panel C, considering only Monetary Policy Reports released at 10 a.m. ET). The econometric method is ordinary least squares with heteroskedasticity and autocorrelation-consistent standard errors in parentheses. ***, **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively.

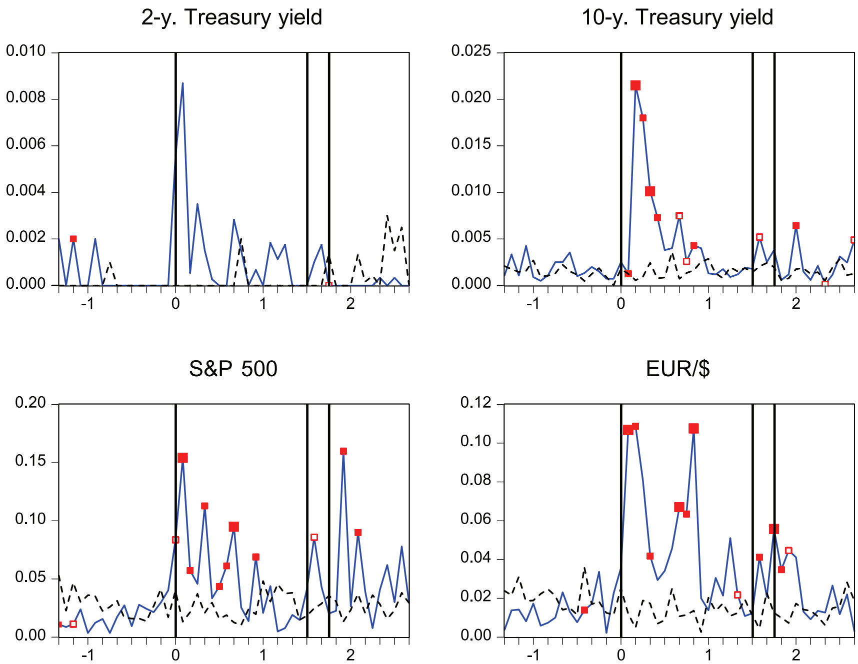
Appendix C. Robust Variance

Figure C1. The Volatility of Asset Prices around the Release of the FOMC Statement



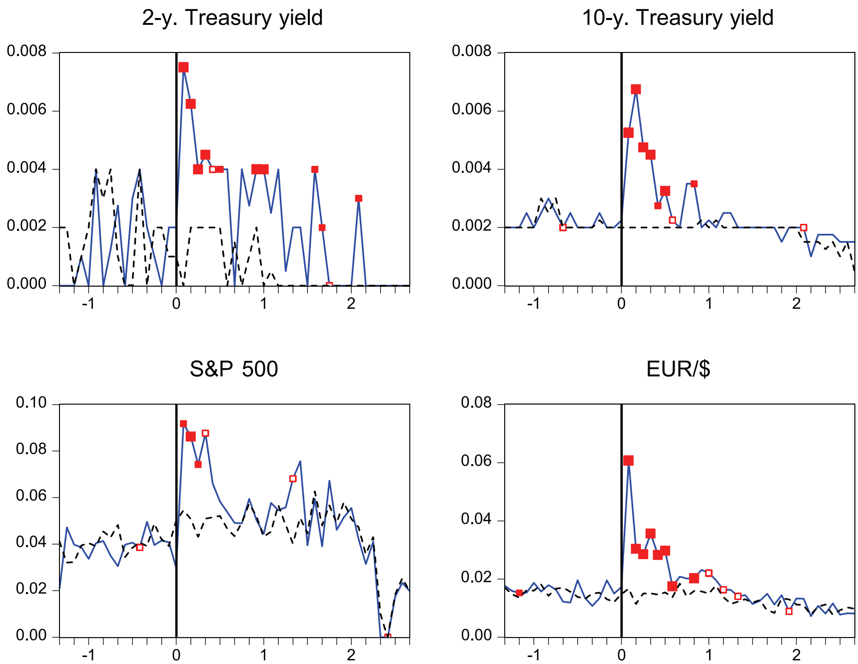
Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release of the FOMC statement on FOMC meeting days with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the FOMC meeting day) with a dashed black line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time of the FOMC minutes, i.e., 2 p.m. ET. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C2. The Volatility of Asset Prices around the Release of the Chairman's Press Conference



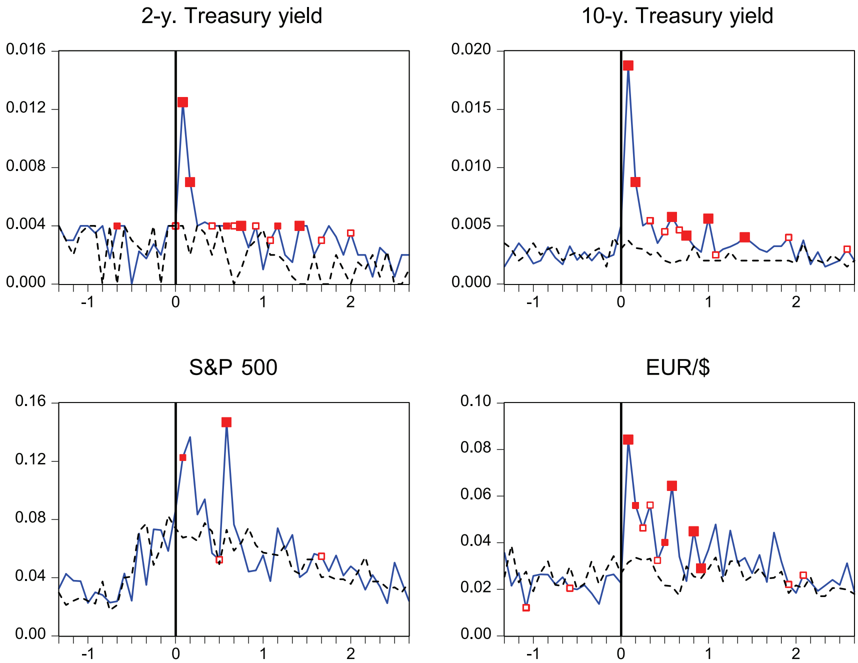
Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the FOMC statement release with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the FOMC minutes release day) with a dashed black line. The sample period is January 2012–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The first vertical line is placed at the release time of the FOMC statement (12:30 p.m. ET); the second vertical line is placed at the release time of the Summary of Economic Projections (2 p.m. ET); and the third vertical line is placed at the start of the Chairman's press conference (2:15 p.m. ET). The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C3. The Volatility of Asset Prices around the Release of FOMC Minutes



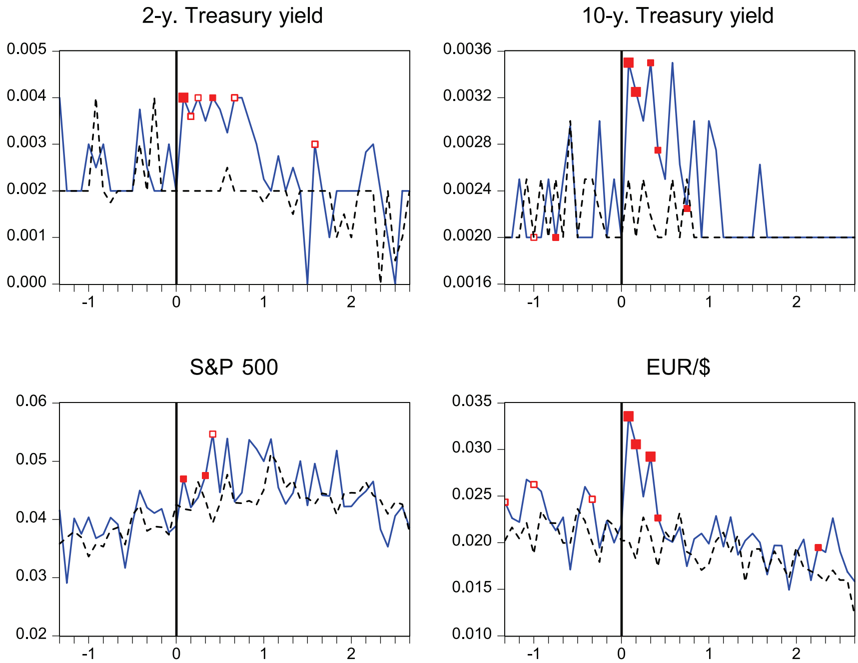
Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the FOMC minutes release with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the FOMC minutes release day) with a dashed black line. The sample period is January 2005–March 2011. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time of the FOMC minutes, i.e., 2 p.m. ET. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C4. The Volatility of Asset Prices around the Chairman's Testimony to Congress



Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the semi-annual Monetary Policy Report to Congress with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

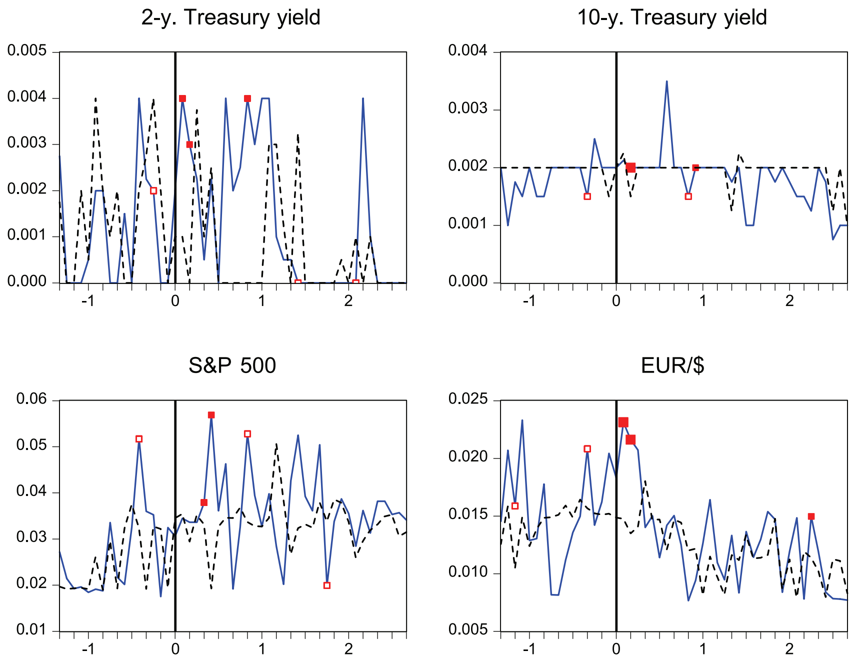
Figure C5. The Volatility of Asset Prices around the Federal Reserve Chairman's Speeches



Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the speeches of the Federal Reserve Chairman with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C6. The Volatility of Asset Prices around Chairman Bernanke's Speeches: Subsamples

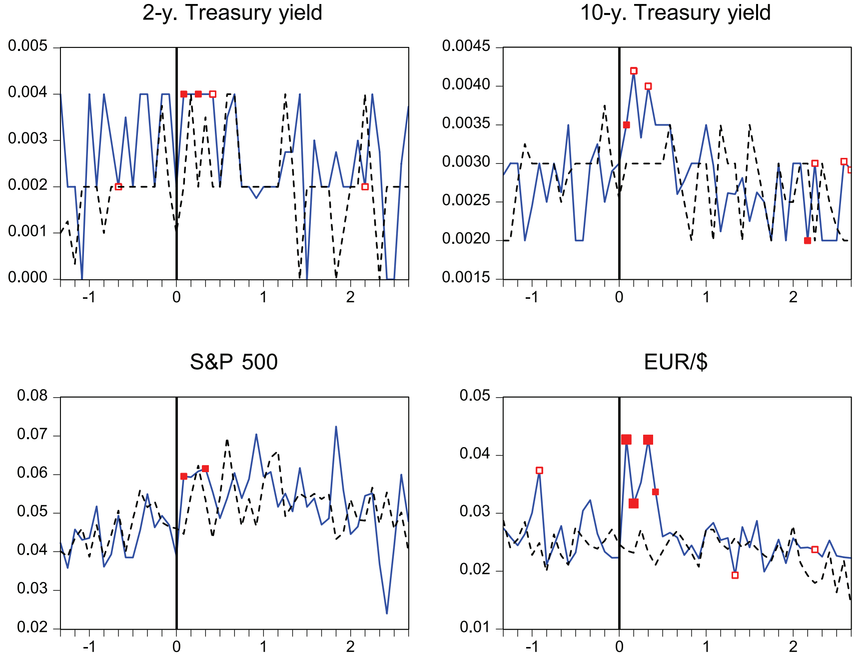
A. Sample: February 2006–December 2007



(continued)

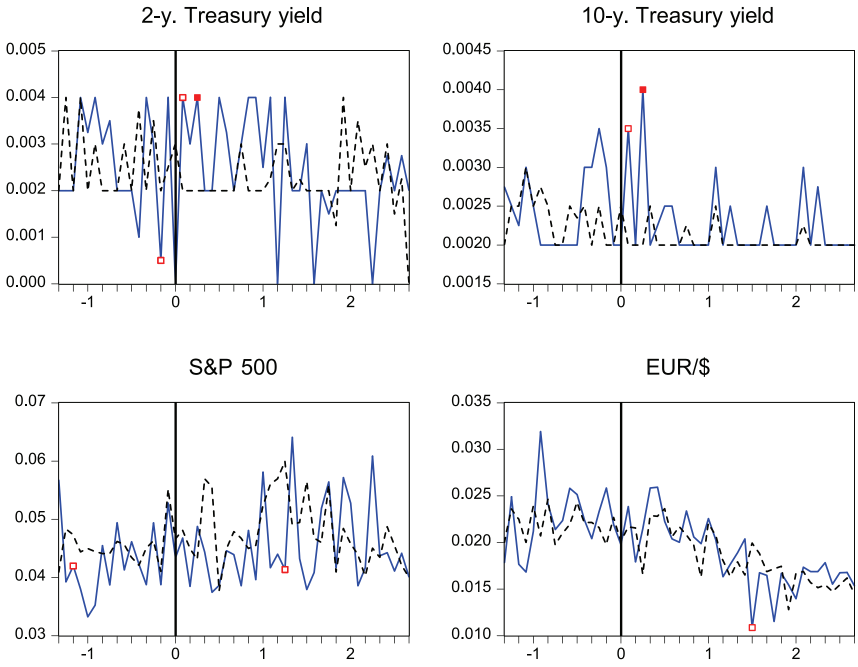
Figure C6. (Continued)

B. Sample: January 2008–December 2012



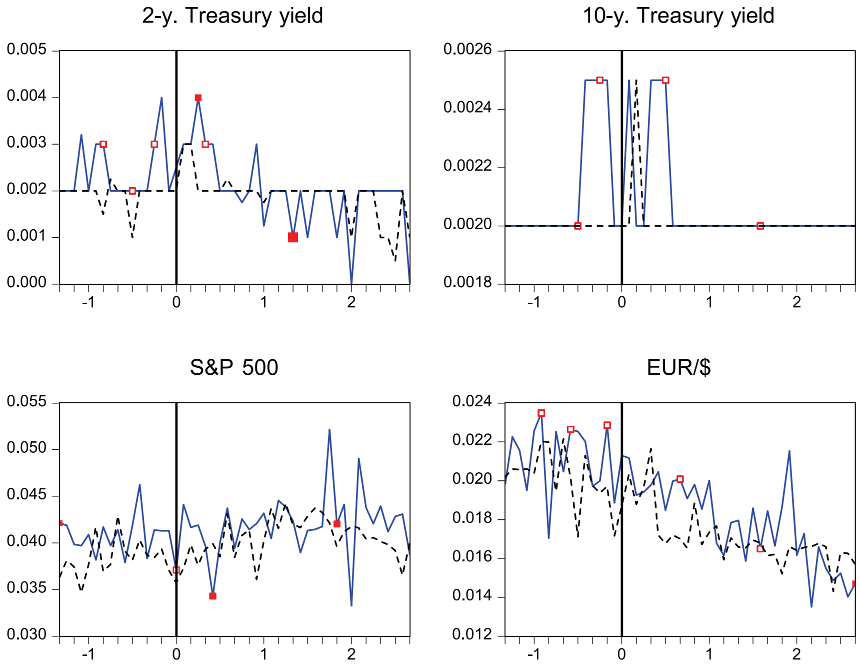
Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the speeches of Federal Reserve Chairman Bernanke with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line for two different samples: February 2006–December 2007 in panel A and January 2008–December 2012 in panel B. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C7. The Volatility of Asset Prices around the FRB Vice Chair's Speeches



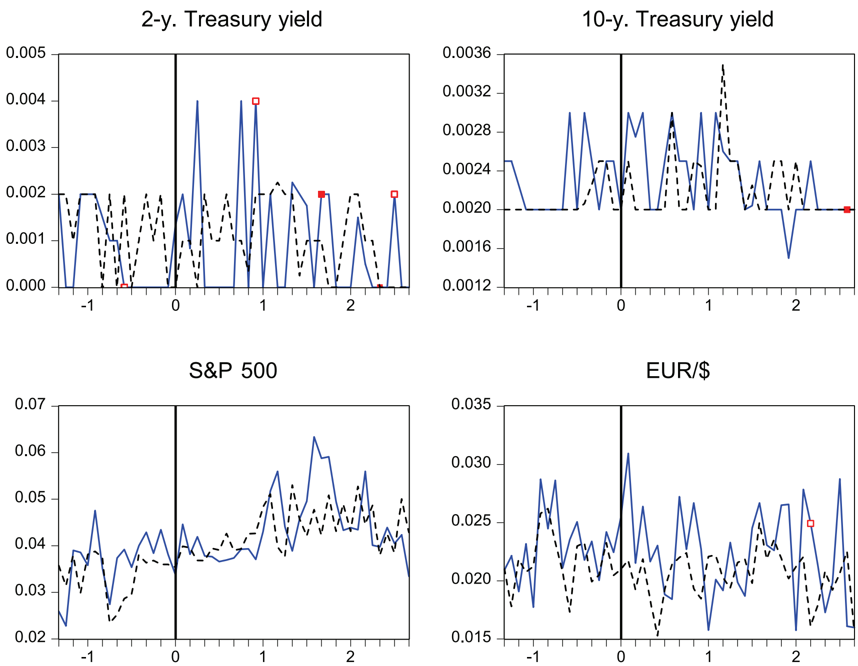
Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the speeches of the Federal Reserve Board Vice Chair with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C8. The Volatility of Asset Prices around the FRB Governors' Speeches



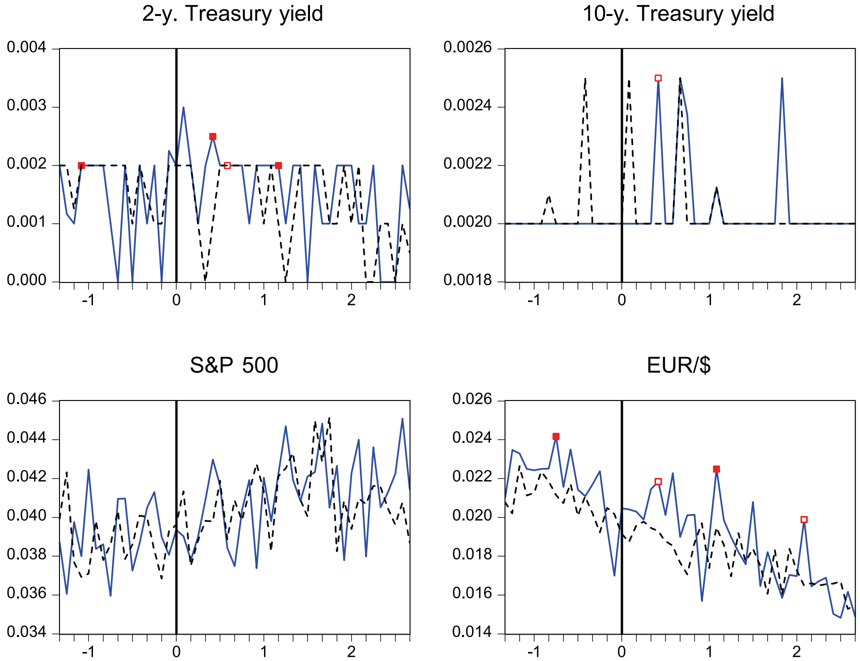
Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the speeches of the Federal Reserve Board Governors with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C9. The Volatility of Asset Prices around the FRBNY President's Speeches



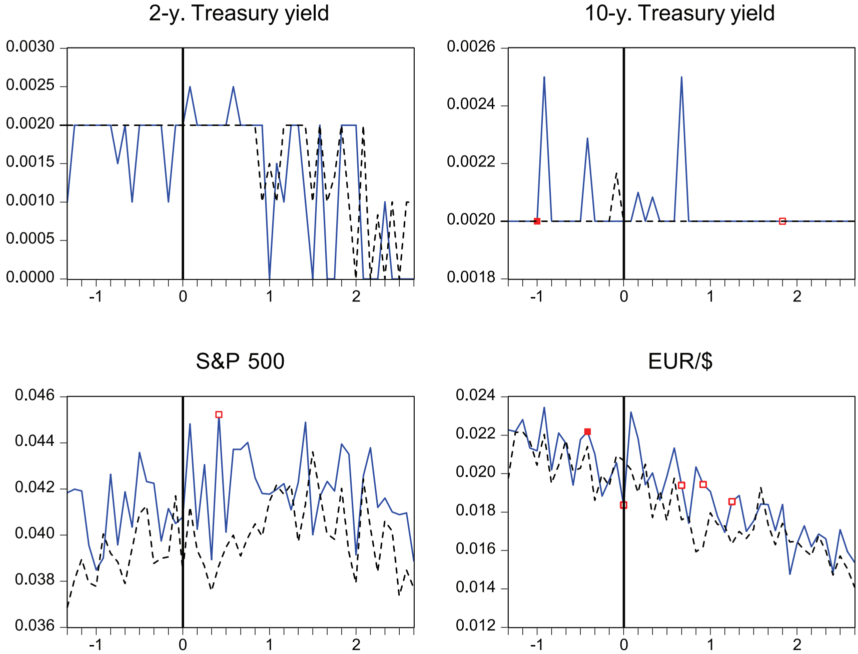
Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the speeches of the Federal Reserve Bank of New York president with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C10. The Volatility of Asset Prices around the Voting Regional Federal Reserve Bank Presidents' Speeches



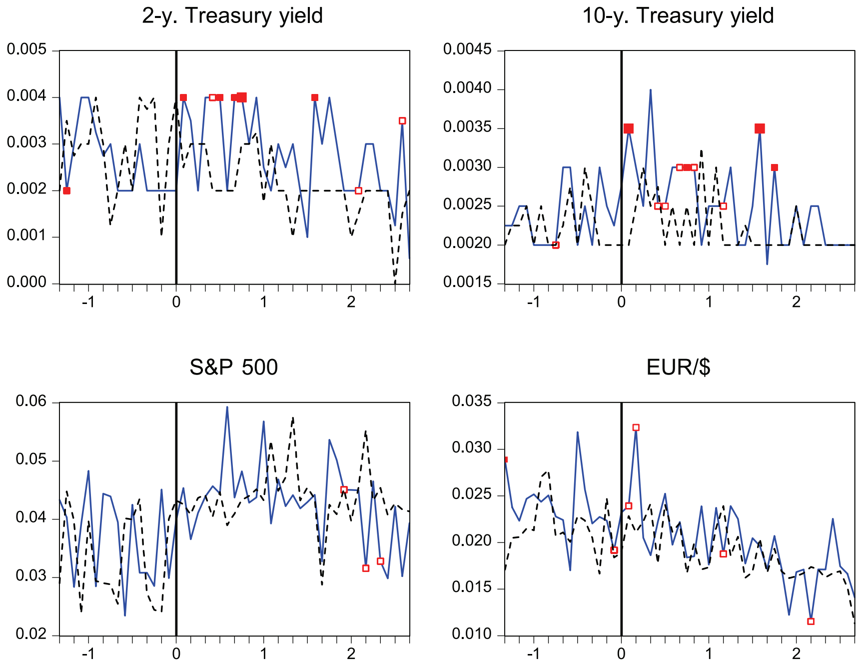
Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the speeches of the voting presidents of the twelve District Federal Reserve Banks with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C11. The Volatility of Asset Prices around Speeches by Non-voting Regional Federal Reserve Bank Presidents



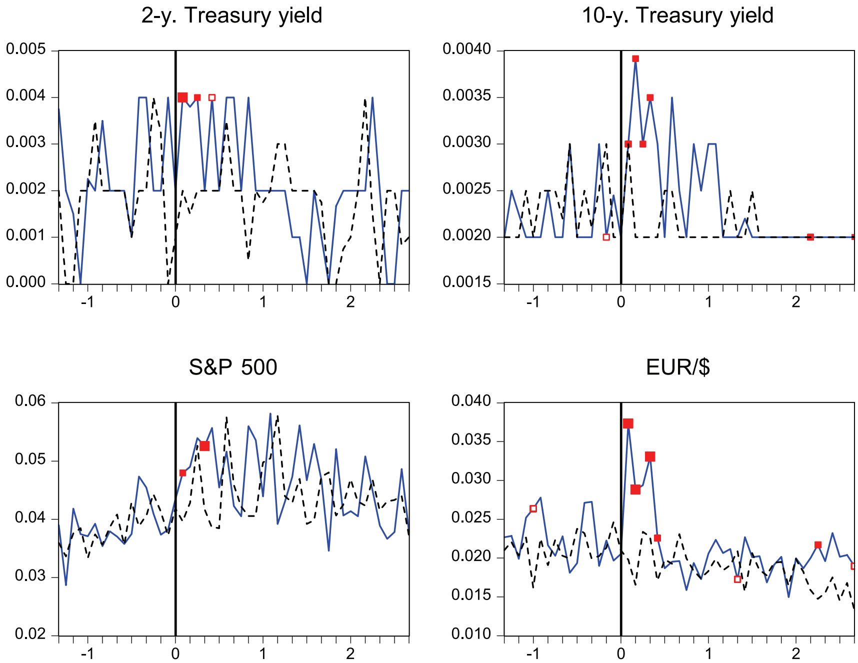
Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the speeches of the non-voting regional Federal Reserve Bank presidents, who also attend FOMC meetings, with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 2001–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C12. The Volatility of Asset Prices around Chairman Greenspan's Speeches



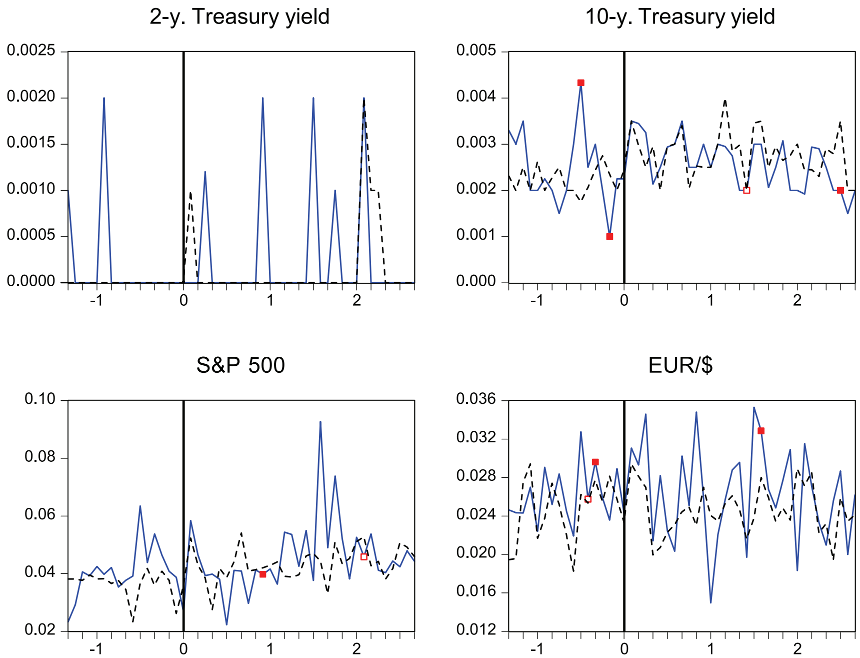
Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the speeches of Federal Reserve Chairman Greenspan with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 2001–January 31, 2006. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C13. The Volatility of Asset Prices around Chairman Bernanke's Speeches



Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the speeches of Federal Reserve Chairman Bernanke with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is February 1, 2006–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.

Figure C14. The Volatility of Asset Prices around FRBNY President Dudley's Speeches



Notes: This figure plots (i) the median absolute deviation of five-minute asset price returns around the release time of the speeches of Federal Reserve Bank of New York President Dudley with a solid blue line and (ii) the median absolute deviation of five-minute asset price returns on control days (the same weekdays and hours of the previous and following week of the release day) with a dashed black line. The sample period is January 27, 2009–December 2012. The interval spans from one hour and twenty minutes before to two hours and forty minutes after the event time. The vertical line is placed at the release time. The Brown and Forsythe (1974) test is employed to test the null hypothesis of equal variances in each subgroup. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level, respectively, whereas small hollow squares denote significance at the 10 percent level.