



INTERNATIONAL JOURNAL OF CENTRAL BANKING

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for the Business Cycle

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Reassessing the Role of Labor Market Institutions for the Business Cycle*

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This paper investigates empirically the effect of labor market institutions (LMIs) on business cycle fluctuations. Most studies, using a cross-country panel approach, have found a weak effect of LMIs on unemployment and, especially, inflation dynamics. In this paper, we estimate an interacted panel VAR for OECD countries, where we allow the dynamics of inflation, unemployment, and the interest rate to vary with the characteristics of the labor market. We find that LMIs have a large and significant effect on both unemployment and inflation dynamics. Stricter employment protection legislation and higher union density mute the reaction of unemployment but increase the response of inflation to external shocks. The opposite effects are found for the generosity of the unemployment benefit system and the extent of the tax wedge. Countries with decentralized wage bargaining manage to absorb shocks through lower variations in unemployment. Our results imply that countries with very rigid or very flexible labor markets can have similar inflation and unemployment dynamics.

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1. Introduction

This paper contributes to a recent body of literature that investigates the scope and importance of labor market institutions (LMIs) for business cycle fluctuations. The empirical literature on the connection between labor market institutions and the level of unemployment is rather vast,¹ but only a few studies have systematically addressed the role of labor market institutions for the business cycle properties of macroeconomic variables. Little consensus emerges from this literature. For instance, in the case of stricter employment protection legislation, some studies find no effect on inflation volatility (Merkl and Schmitz 2011; Rumler and Scharler 2011) or output volatility (Rumler and Scharler 2011), while others find a negative effect on unemployment or output volatility (Merkl and Schmitz 2011; Faccini and Rosazza Bondibene 2012) or an inverted U-shaped effect on the relative unemployment to output volatility (Lochner 2014). The available evidence is similarly inconclusive in the case of benefit replacement rates or for the impact of unions on business cycle dynamics.²

Most of these papers use a cross-country panel approach based on the regression of business cycle volatilities on selected LMIs and controls. There are several reasons why this approach may not fully capture the relationship between LMIs and macroeconomic outcomes. First, there is the risk that the association of LMIs with fluctuations at higher frequency washes out when working with five-year averages or volatilities. Second, it may be important to control for the magnitude and types of shocks that hit different economies. Third, typically this framework does not allow to control for systematic differences in the monetary policy response to inflation and unemployment dynamics in a satisfactory way. Therefore, studies that rely on this approach likely face more difficulties in identifying robust relationships between various dimensions of the labor market and business cycle fluctuations.

¹See, for instance, Elmeskov, Martin, and Scarpetta (1998), Blanchard and Wolfers (2000), Bertola, Blau, and Kahn (2002), or Nickell, Nunziata, and Ochel (2005), to name but a few.

²See table 1 for a summary of this literature.

We try to overcome these hurdles by estimating an interacted panel VAR (Towbin and Weber 2013; Sa, Towbin, and Wieladek 2014) for a panel of twenty OECD countries for the period from 1970 to 2013. The approach allows the response coefficients in the VAR to change deterministically with the characteristics of the labor market. Moreover, this technique allows us to fully exploit the time dimension of the data and to control for different shocks and policy responses. We focus on two external shocks—an oil price shock and a world demand shock—and analyze how the responses of the unemployment and the inflation rates to these shocks vary under different types and degrees of labor market rigidities.

Labor market institutions are found to have a strong and significant effect on business cycle dynamics. We find that stricter employment protection legislation (EPL), by making it more costly to fire workers, induces firms to absorb shocks through price changes. Therefore, higher EPL reduces unemployment volatility but increases inflation volatility, as suggested by the models of Thomas and Zanetti (2009) and Zanetti (2011). More generous unemployment benefits have the opposite effect. Higher benefits improve workers' outside option, reduce the responsiveness of wages and inflation to aggregate fluctuations, and increase unemployment volatility (see, e.g., Thomas and Zanetti 2009 and Campolmi and Faia 2011). Similarly, a higher tax wedge, by increasing the workers' reservation wage, reduces inflation volatility and increases unemployment volatility.

Interestingly, the effects of trade unions partially depend on the shocks hitting the economy. We consider two indicators capturing the effects of trade unions: union density and the degree of wage-bargaining centralization. High union density amplifies the response of inflation to external shocks and slightly reduces the unemployment response, though the latter effect is significant only in the case of the external demand shock. These results support the claim that in countries with high unionization rates, workers may be able to extract greater compensation following a cost or demand shock, and thus cause a wage-price spiral. On the contrary, the effects of the degree of centralization in the wage-bargaining process crucially depend on the nature of the shock. Following an oil price shock, high centralization amplifies inflation volatility, while it has no significant effect on unemployment fluctuations. Following a demand

shock, instead, centralization increases unemployment fluctuations but reduces inflation adjustment. This confirms the importance of controlling for the magnitude and type of shocks hitting the economy, because the strategy of trade unions, and the interaction between unions, governments, and central banks, may change depending on the nature of the shocks.

Our results suggest that it can be misleading to focus the attention on a unidimensional characterization of the labor market.³ We show that the inflation and unemployment responses to shocks in countries with overall rather rigid labor markets (e.g., Belgium) are not significantly different from the response in economies with relatively flexible labor markets (e.g., Switzerland or the United States). Finding no difference between “rigid” and “flexible” economies does not imply that LMIs are irrelevant for business cycle dynamics, but is simply a consequence of the offsetting effects of different institutions. The starkest contrast in the responses of inflation and unemployment to shocks can be found in those countries with institutions that limit price adjustments (e.g., the Netherlands) compared with those countries with institutions that limit quantity adjustments (e.g., Portugal). Quantity adjustments are found to be limited in countries with high EPL, high union density, low unemployment benefits, and a low tax wedge. Price adjustments are found to be limited in countries with the opposite constellation of LMIs.

The findings of our study support a related and growing theoretical literature that incorporates the search-and-matching model of the labor market into the standard New Keynesian model.⁴ While most of these models imply a strong effect of labor market institutions on unemployment fluctuations, there is less agreement regarding the effect of LMIs on inflation dynamics. For example, Campolmi and Faia (2011) claim that differences in the generosity of unemployment benefits can partly explain inflation volatility differentials among euro-area countries. Thomas and Zanetti (2009) find instead that the effect of labor market reforms (lower benefits and/or firing costs) on inflation dynamics is likely to be small. Christoffel,

³See, e.g., Bertola and Rogerson (1997) for a similar argument

⁴See, e.g., Christoffel and Linzert (2005), Walsh (2005), Krause and Lubik (2007), Thomas (2008), Gertler and Trigari (2009), Thomas and Zanetti (2009), Trigari (2009), and Blanchard and Galí (2010).

Kuester, and Linzert (2009) argue that only institutions that create nominal wage stickiness and affect directly wage dynamics have a non-negligible effect on inflation; the importance of other labor market rigidities (hiring costs, unemployment benefits, workers' bargaining power) is rather limited. Our results are qualitatively consistent with these contributions but, importantly, suggest that LMIs have a significant impact not only on unemployment fluctuations but also on inflation dynamics.

The remainder of this paper is structured as follows. Section 2 outlines the estimation strategy. Section 3 presents the main results, and section 4 concludes. Further details on the data and additional results are available in an external appendix on the IJCB website (<http://www.ijcb.org>).

2. Estimation Approach

The following sections present the interacted panel VAR (IPVAR) approach in its general form, its application in the context of this analysis, and a description of the data.

2.1 An Interacted Panel VAR Approach

Our estimation strategy is motivated by the structural representation of a standard log-linearized solution of a rational expectation DSGE model:⁵

$$\mathbf{A}_0(\Lambda) \mathbf{y}_t = \mathbf{A}_1(\Lambda) \mathbf{y}_{t-1} + \mathbf{B}_0(\Lambda) \mathbf{z}_t \quad (1)$$

$$\mathbf{C}_0 \mathbf{z}_t = \mathbf{C}_1 \mathbf{z}_{t-1} + \varepsilon_t, \quad (2)$$

where the vector $\mathbf{y}_t$ denotes the endogenous variables, $\mathbf{z}_t$ denotes a vector of AR(1) shock processes, and Λ is a vector of policy parameters with elements λ_j that correspond to the individual LMIs of the economy.⁶ Matrices labeled $\mathbf{A}$ govern the dynamics among dependent variables, matrices labeled $\mathbf{B}$ govern the impact of shocks on

⁵We would like to thank an anonymous referee for suggesting this analogy.

⁶Notice that we assume that the LMIs do not respond endogenously to the state of the economy. We also assume shock processes to be independent of the policy parameters, i.e., the latter affect only the transmission of shocks to the endogenous variables.

endogenous variables, and matrices labeled $\mathbf{C}$ determine the dynamics of shocks. Subscripts refer to the relevant lag order of the corresponding variables.

Because there is often limited variation in Λ for an individual country, most studies analyzing the effect of different labor market structures on business cycle dynamics adopt a cross-country panel approach and estimate a model of the form

$$\ln \sigma_{i,t} = \beta \Lambda_{i,t} + \gamma X_{i,t} + e_{i,t}, \quad (3)$$

where $\ln \sigma_{i,t}$ stands for the log variance of the dependent variable of interest for country i and period t , $X_{i,t}$ is a vector of controls potentially including time and country fixed effects, and $e_{i,t}$ stands for an error term. Table 1 provides a summary of the recent empirical literature, which is mostly based on this approach. Several of these studies find a rather weak effect of most LMIs on business cycle volatilities. In an external appendix, we use a similar approach to estimate directly the effects of LMIs on inflation and unemployment volatilities with our data set. Our results confirm the relatively weak and unstable link between macroeconomic volatilities and LMIs: while several indicators are significant at times, coefficients change sign, are insignificant, or are not robust to the inclusion of country fixed effects.

The failure to find a robust relationship does not necessarily prove the irrelevance of LMIs for business cycle dynamics. First, several studies work with five-year periods to compute the volatility of the dependent variable. This may mask an effect of LMIs on macroeconomic fluctuations at higher frequency. Second, this approach makes it difficult to control for the fact that different countries are likely to be exposed to different types or magnitudes of shocks. Third, a linear regression of volatility on LMIs could mask a more nuanced relationship between LMIs and macroeconomic outcomes, as the variance of the system (1) and (2) implies a possibly strong non-linear relationship between LMIs and the volatility of the dependent variable.⁷

⁷The general solution for the volatility of the dependent variable of the system (1) and (2) is given by $\text{vec}(\Sigma_y) = [\mathbf{I} - \widetilde{\mathbf{A}}_1(\Lambda) \otimes \widetilde{\mathbf{A}}_1(\Lambda)]^{-1} [\widetilde{\mathbf{B}}_0(\Lambda) \otimes \widetilde{\mathbf{B}}_0(\Lambda)] \text{vec}(\Sigma_z)$, where $\widetilde{\mathbf{A}}_1 = \mathbf{A}_0^{-1} \mathbf{A}_1$ and $\widetilde{\mathbf{B}}_0 = \mathbf{A}_0^{-1} \mathbf{B}_0$.

Table 1. Summary of Recent Empirical Studies Examining the Effect of Labor Market Institutions (LMIs) on Business Cycles

Study	Countries	Period	Estimation Strategy	Dependent Variables	LMIs Used	Results
Bowdler and Nunziata (2007)	20 OECD Countries	1961 to 1995	Panel data analysis	CPI inflation	Coordination of wage bargaining and union density	High degree of coordination dampens inflation adjustment, while union density amplifies inflation responses.
Fonseca, Patureau, and Sopraseuth (2010)	20 OECD Countries	1964:Q1 to 2003:Q4	Panel data analysis	Business cycle synchronization (i.e., cross-country GDP correlation)	EPL, union density, coordination of wage bargaining, unemployment benefits, tax wedge components (employment tax rates, direct and indirect tax rates).	Disparities in EPL and direct taxation lower international co-movement, while divergences in union density, unemployment benefits, and indirect taxation increase cross-country correlations.
Rumler and Scharler (2011)	20 OECD Countries	1970:Q1 to 2006:Q4	Panel data analysis	Inflation and output volatilities (standard dev. of five-year periods)	EPL, union density, coordination of wage bargaining	Union density increases output volatility, while coordination of wage bargaining lowers inflation volatility. Other LMIs have no significant effect.
Merkel and Schmitz (2011)	11 Euro-Area Countries	1999:Q1 to 2008:Q2	Cross-country regression	Inflation and output gap volatilities	EPL, unemployment benefit replacement rates	EPL reduces output volatility, while higher replacement rates increase output volatility. No clear effect on inflation volatility.
Faccini and Rosazza Bondibene (2012)	20 OECD Countries	1975:Q1 to 2009:Q4	Panel data analysis	Relative unemployment volatility (i.e., the ratio $\text{vol}(u)/\text{vol}(y)$)	Temporary/permanent EPL, coordination of wage bargaining, union coverage/density, tax wedge, unempl. benefit replacement rates and duration.	EPL and union density strongly reduce the sensitivity of unemployment to output changes; union coverage increases it. Benefit replacement rates, benefit duration, and the tax wedge have a limited impact on the sensitivity of unemployment fluctuations.

(continued)

Table 1. Continued

Study	Countries	Period	Estimation Strategy	Dependent Variables	LMIs Used	Results
Lochner (2014)	20 OECD Countries	1985:Q1 to 2012:Q4	Panel data analysis	Relative unemployment volatility (i.e., the ratio $\text{vol}(u)/\text{vol}(y)$)	Temporary/permanent EPL, union density, coordination/centralization of wage bargaining and net replacement rates	EPL index for permanent contracts has a non-linear, inverted U-shaped effect on relative unemployment volatility. Coordination, union density, and replacement rates also have a negative effect. Centralization not significant.
Gnocchi, Lagerborg, and Pappa (2015)	19 OECD Countries	1971:Q1 to 2007:Q4	(1) Spearman rank correlations; (2) difference-in-differences approach	(1) Decade average business cycle indicators; (2) macroeconomic performances of reformers and non-reformers	Replacement rates, labor unions (density, coverage, concentration, centralization), wage bargaining process (coordination, government involvement, level at which bargaining takes place, coverage extension of bargained wage) and EPL collapsed in statistical factors based on principal components analysis.	(1) Spearman partial rank correlations: more flexible institutions are associated with lower business cycle volatility. (2) Reform episodes: wage bargaining reforms increase the correlation of the real wage with labor productivity and the volatility of unemployment. EPL reforms increase the volatility of employment and decrease the correlation of the real wage with labor productivity. Reforms reducing replacement rates make labor productivity more procyclical.

In this paper we propose an alternative approach—the interacted panel VAR (Towbin and Weber 2013, Sa, Towbin, and Wieladek 2014).⁸ The IPVAR approach pools estimates across a sample of countries and estimates directly how the matrices $\mathbf{A}_0$, $\mathbf{A}_1$, and $\mathbf{B}_0$ of the system (1) and (2) depend on the policy parameters (Λ). Intuitively, the IPVAR estimates a first-order approximation of these matrix functions around the sample average of Λ , $\bar{\Lambda}$. That is, the IPVAR approximates

$$\mathbf{A}_l(\Lambda) \approx \mathbf{A}_l(\bar{\Lambda}) + \sum_{j=1}^h \frac{\partial \mathbf{A}_l}{\partial \lambda_j}(\bar{\Lambda}) (\lambda_j - \bar{\lambda}_j) \text{ for } l \in (0, 1) \quad (4)$$

and similarly for $\mathbf{B}_0$. h refers to the dimension of the vector of policy parameters.

In practice, the main difference of the IPVAR to a panel VAR is that the regressand is regressed not only on the regressors at various lags but also on the regressors interacted with the respective labor market institutions. Thus, the response coefficients are allowed to change deterministically with the characteristics of the economy. This permits controlling for different shocks and monetary policy responses, and allows analyzing the impulse responses and volatilities of macroeconomic variables for varying constellations of LMIs. It is a more encompassing estimation of the effect of LMIs on business cycle dynamics, because interactions among the LMIs affect the impulse response functions and the variances of the dependent variables in the IPVAR. However, there are also some potential limitations of the approach. The most important one is that LMIs may be endogenous to the shocks hitting the economy—a potential limitation we share with almost all the empirical literature on the effects of LMIs on business cycle fluctuations. In the main specification, we try to partially control for this by using lagged policy variables in the estimation, but we acknowledge that our strategy is based on the assumption that business cycle fluctuations have a negligible effect on the choice of LMIs. A second potential limitation is the linearity assumption embedded in our IPVAR as reflected by the

⁸For a related approach, see also Loayza and Raddatz (2007), Georgiadis (2014), and Nickel and Tudyka (2014).

approximation equation (4).⁹ This assumption could be relaxed by considering various non-linear combinations of the different LMIs.¹⁰ However, it is very difficult to determine a priori the correct non-linear relationship and relevant interaction terms. Moreover, depending on the number of observations and of policy parameters in the estimation, overfitting of the model is a concern.¹¹ We therefore leave the analysis of the importance of non-linearities and of the assessment of the endogeneity of LMIs to future research.

2.2 Estimation and Identification

The IPVAR representation of the estimated model considered here is given by¹²

$$\begin{pmatrix} C_0 & 0 \\ B_{0,t} & A_{0,t} \end{pmatrix} \begin{pmatrix} \mathbf{s}_{i,t} \\ \mathbf{y}_{i,t} \end{pmatrix} = \mu_i + \sum_{l=1}^L \begin{pmatrix} C_l & 0 \\ B_{l,t} & A_{l,t} \end{pmatrix} \begin{pmatrix} \mathbf{s}_{i,t-l} \\ \mathbf{y}_{i,t-l} \end{pmatrix} + \begin{pmatrix} \varepsilon_{i,t}^S \\ \varepsilon_{i,t}^Y \end{pmatrix}, \quad (5)$$

where $\mathbf{y}_{i,t}$ is the vector of endogenous variables for country i , $\mathbf{s}_{i,t}$ is a vector of external variables, $\varepsilon_{i,t}^S$ and $\varepsilon_{i,t}^Y$ are the structural shocks, and μ_i are a set of country fixed effects. The vector of dependent variables $\mathbf{y}_{i,t}$ includes with the (annualized) inflation rate and the unemployment rate the two main variables considered in studies on

⁹If the relationship between the propagation matrices and the policy variables is not linear, the approximation (4) might lead the residuals to be correlated with right-hand-side variables. In a recent study, Lochner (2014) explores the role of non-linearity for the case of EPL and finds that more stringent EPL has an inverted U-shaped effect on the ratio of unemployment to output volatility.

¹⁰Towbin and Weber (2013) consider only two policy parameters but allow for their interaction. Georgiadis (2014) allows for polynomials of the relevant policy parameters.

¹¹It should also be noted that the dimensionality increases more than one-for-one depending on the number of dependent variables in $\mathbf{y}_t$ and the number of lags considered in the VAR.

¹²The representation corresponding to (1) and (2) is given by $\mathbf{z}_t = (s_t \ s_{t-1} \ \varepsilon_t^Y)'$, $\mathbf{A}_0(\Lambda) = A_{0,t}$, $\mathbf{A}_1(\Lambda) = A_{1,t}$, $\mathbf{B}_0(\Lambda) = (-B_{0,t} \ B_{1,t} \ I)$, $\mathbf{C}_0 = \begin{pmatrix} C_0 & 0 & 0 \\ 0 & I & 0 \\ 0 & 0 & I \end{pmatrix}$, $\mathbf{C}_1 = \begin{pmatrix} C_1 & 0 & 0 \\ I & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$.

the effect of LMIs on business cycle dynamics and with the three-month short-term Treasury-bill rate a third factor, which controls for varying monetary policy responses. The vector of external variables, $\mathbf{s}_{i,t}$, includes the log-difference of the oil price and a measure of world demand growth, which we proxy by the log-difference of the sum of real GDP in the *other* countries ($\Delta \ln M_{i,t} = \Delta \ln \sum_{j \neq i}^I GDP_{j,t}$).¹³

We analyze the role of LMIs for the adjustment dynamics by allowing the coefficients of the A matrices and B matrices to vary with the labor market indicators:¹⁴

$$A_{l,t} = \bar{A}_l + \alpha_l \cdot \Lambda_{i,t} \quad (6)$$

$$B_{l,t} = \bar{B}_l + \beta_l \cdot \Lambda_{i,t}, \quad (7)$$

where $l = 0, 1, \dots, L$ refers to the lag order. The estimated $\bar{A}, \bar{B}, \alpha$, and β coefficients can be used to evaluate the A and B coefficients for any possible combination of LMIs, reflecting the dynamic responses of an economy with a particular labor market structure. We characterize the labor market ($\Lambda_{i,t}$) using five indicators: (i) the strictness of employment protection legislation (EPL); (ii) the generosity of the unemployment benefit system, as measured by the benefit replacement rates (BRR); (iii) the tax wedge, which is a measure of the difference between labor costs to the employer and the net take-home pay of the employee (TW); (iv) the degree of unionization as measured by the percentage of workers affiliated with a union (UDENS); and (v) the centralization of wage bargaining in the economy (CEW). Even though this is not an exhaustive list of indicators to describe the overall design of the labor market, these five dimensions cover the most widely used aspects in studies on the effect of labor market institutions on macroeconomic developments.¹⁵

¹³For instance, the external demand shock for Germany is the growth rate of the sum of all countries' real GDP excluding Germany.

¹⁴The representation corresponding to equation (4) is given by $\mathbf{A}_l(\Lambda) = A_{l,t}$, $\bar{\mathbf{A}}_l(\Lambda) = \bar{A}_l$, and $\sum_{j=1}^h \frac{\partial \mathbf{A}_l}{\partial \lambda_j}(\bar{\Lambda})(\lambda_j - \bar{\lambda}_j) = \alpha_l \cdot \Lambda_{i,t}$; similarly for $\mathbf{B}$.

¹⁵In our choice of labor market institutions, we are constrained by two main factors: data availability, in the sense that we need a sufficiently long series of LMIs for a sufficiently large number of countries, and a sort of dimensionality curse. Adding more LMIs, in fact, would multiply the number of coefficients to estimate and would reduce the sample size due to more limited data availability of other LMI measures, which taken together would significantly reduce the degrees of freedom of our analysis.

We focus on two external shocks—an oil price shock and a world demand shock. This partial identification strategy is motivated by three main reasons: First, using external shocks allows us to focus on the role of LMIs for the adjustment process, avoiding a discussion of the appropriateness of one over the other identification scheme in individual countries. Second, we focus on an oil price and a world demand shock because they can be interpreted as supply and demand shocks. Third, the focus on external shocks implies that the heterogeneity that is observed in the response variables is unrelated to the shock itself.¹⁶ To identify the oil price shock, we follow Blanchard and Galí (2007) and assume the oil price to be contemporaneously unaffected by the remaining variables in the system. All other variables (including world demand) are contemporaneously affected by the oil price. We allow the lagged values of the world demand to impact the oil price to control for demand-driven price increases. The other variables have no impact on world demand and oil prices.¹⁷ Our identifying assumptions for equation (5) are thus given by constraining the matrix C_0 to be lower triangular. While the literature has proposed alternative identification schemes (see, for instance, Kilian 2008), we find our results to be robust to a change in the ordering of the two external shocks.

Under the described assumptions and identifying restrictions, we can consistently estimate (5), (6), and (7) using OLS. Due to the non-linearity of the impulse responses in the coefficient estimates, analytical standard errors may be inaccurate. To address this issue we use bootstrapped standard errors as proposed by Runkle (1987), adjusted for the fact that we are dealing with a panel, and make use of interaction terms.¹⁸ All estimations are performed using quarterly

¹⁶For instance, using country-by-country estimates and comparing the dynamic responses of inflation and unemployment to an identified (country-specific) shock—say, a domestic demand shock—potentially blurs the role of LMIs and different shock dynamics across countries.

¹⁷The underlying exogeneity assumption implies that each single country is too small to affect world demand and prices. Relaxing this assumption by allowing countries to affect world variables with a lag of one quarter has again no implications for the findings in this study.

¹⁸The procedure may be described in the following way. (i) Estimate (5), (6), and (7) by (restricted) OLS. (ii) Draw randomly from the matrix of (structural) errors $\hat{\varepsilon}_{i,t}$ a vector of errors $\hat{\varepsilon}_{i,\tilde{t}}$. (iii) Use $\hat{\varepsilon}_{i,\tilde{t}}$ and the initial observations of the sample and the estimates of $\hat{A}_l$, $\hat{B}_l$, and $\hat{C}_l$ to simulate recursively $\hat{Y}_{i,1}$. (iv) After

data and a lag length of four as suggested by the Schwarz criteria. Unlike the other variables, labor market indicators are available on an annual or biannual basis. This makes an assumption about the timing of the influence of a change in the LMI on business cycle dynamics necessary. We choose the timing such that a change in an LMI is always effective as of the first quarter of the respective year in which a change in the indicator occurred. This date may not coincide exactly with the respective change in the legislation, and different timings may be chosen (e.g., the last quarter of the respective year). However, the exact timing appears to have no influence on our findings. Finally, to control for the potential endogeneity of LMIs, we use four-quarter lags for LMIs. Using contemporaneous LMI indicators, results are close to identical.

2.3 Data

Data come from various sources. The unemployment rate, the annual inflation rate, the short-term interest rate, and the Brent oil price in U.S. dollars are from the OECD Economic Outlook quarterly statistics. The seasonally adjusted real GDP constant PPP U.S. dollar series, used to construct the world demand shock, are taken from the OECD Quarterly National Accounts database. Labor market indicators are taken from the CEP-OECD institutions database (Nickell 2006). The original data set contains annual observations until 2004. We extend the data until 2013 using information from the OECD; the ICTWSS Database on Institutional Characteristics of Trade Unions, Wage Setting, State Intervention and Social Pacts (Visser 2013); and our own calculations as described in the external appendix on the IJCB website.

The sample includes twenty countries, corresponding to the twenty countries in the original CEP-OECD database. Data on labor market indicators are close to complete with 846 annual observations

the first period is simulated for all variables in the system, interact the variables with the interaction terms and now repeat steps (ii) and (iii) as many times as there are errors. (v) The artificial sample is then used to reestimate the coefficients of (5), (6), and (7) with which the IRFs are constructed. (vi) This exercise (steps (ii)–(v)) is repeated 500 times and confidence intervals are the p^{th} and $1 - p^{th}$ value of the 500 constructed IRFs. In the following we use $p = 5\%$ such that responses are drawn with a 90 percent confidence interval.

out of 860 ($= 43 \cdot 20$) possible observations. Our sample covers the period from 1970:Q1 to 2013:Q4 unless otherwise indicated, and includes the following countries:¹⁹ Austria, Australia, Belgium, Canada, Denmark (1979:Q2–2013:Q4), Finland, France, Germany, Ireland (1984:Q1–2013:Q4), Italy (1971:Q1–2013:Q4), Japan, New Zealand (1974:Q1–2013:Q4), the Netherlands, Norway, Portugal (1978:Q1–2013:Q4), Spain (1980:Q1–2013:Q4), Sweden (1982:Q1–2013:Q4), Switzerland (1974:Q1–2013:Q4), the United Kingdom, and the United States.

Table 2 summarizes statistics for the labor market structures of all the countries in our sample. We divide OECD countries into five groups: Anglo-Saxon, Continental Europe, Mediterranean, Scandinavia, and Japan. Anglo-Saxon countries are characterized by flexible labor markets along all five dimensions we consider. For the United States, in particular, the LMIs are always below the 20th percentile of the distribution of LMIs across all countries in the sample. At the other extreme, Scandinavian countries are characterized by high levels of almost all LMIs—in particular, of the unemployment benefits, the tax wedge, and union density. The only exception is EPL, which takes a value close to the median. Continental European labor markets are in between the Scandinavian and the Anglo-Saxon models and are characterized, on average, by values very close to the median LMIs. There are, however, many differences across countries, with Belgium having one of the most rigid labor markets and Switzerland one of the most flexible ones. Finally, Mediterranean countries are characterized by very high levels of EPL, centralized wage setting, and relatively low generosity of unemployment benefits.

3. Results

Based on the IPVAR estimation results for the sample of twenty OECD countries, we analyze the role of LMIs for macroeconomic fluctuations, conducting three exercises: First, we analyze to which extent the responses of unemployment and inflation to a given shock vary with specific aspects of the labor market. Second, we assess the

¹⁹The individual countries' starting points are affected by missing labor market and interest rate data.

Table 2. Average Labor Market Institution Values over Sample Period, by Country

Country Group	Country	Labor Market Institutions				
		EPL	BRR	TW	UDENS	CEW
Anglo-Saxon	Australia	0.34	22.86	36.39	35.42	1.83
	Canada	0.27	16.92	43.70	31.73	1.00
	Ireland	0.30	30.16	38.32	44.63	2.44
	New Zealand	0.36	28.72	38.04	40.88	1.45
	United Kingdom	0.20	18.65	41.90	37.21	1.23
Continental Europe	United States	0.07	13.68	32.39	16.98	1.00
	<i>Average</i>	0.26	21.83	38.46	34.48	1.49
	Austria	0.64	28.28	55.19	44.88	2.00
	Belgium	0.94	41.55	55.58	51.28	2.24
	France	0.93	33.65	61.85	12.60	1.85
	Germany	0.97	26.99	51.65	28.84	2.00
	Netherlands	0.83	47.36	52.30	26.89	2.15
	Switzerland	0.34	21.87	36.21	22.67	1.88
Scandinavian	<i>Average</i>	0.77	33.28	52.13	31.19	2.02
	Denmark	0.64	49.69	60.62	72.29	2.23
	Finland	0.73	31.14	59.20	70.48	2.52
	Norway	0.93	34.05	60.69	55.47	2.45
	Sweden	0.87	28.04	71.39	76.81	2.34
Mediterranean	<i>Average</i>	0.79	35.73	62.97	68.76	2.38
	Italy	1.01	15.03	54.47	39.86	2.25
	Portugal	1.24	26.11	42.54	30.90	2.36
	Spain	1.17	29.45	44.39	15.30	2.46
	<i>Average</i>	1.14	23.53	47.13	28.69	2.36
Other	Japan	0.65	11.19	32.17	25.79	1.00
Overall Sample	20 pct (Low)	0.32	17.79	37.21	24.23	1.34
	Median	0.69	28.16	48.02	36.32	2.08
	80 pct (High)	0.95	33.85	59.91	53.38	2.40

impact of individual LMIs on the aggregate volatility of inflation and unemployment. This allows us to compare our results with the results of studies that estimate directly the effects of LMIs on macroeconomic volatilities. Third, we ask how important is the interplay of different labor market institutions and study how business cycle dynamics change when we vary multiple LMIs at the same time, approximating relevant country examples.

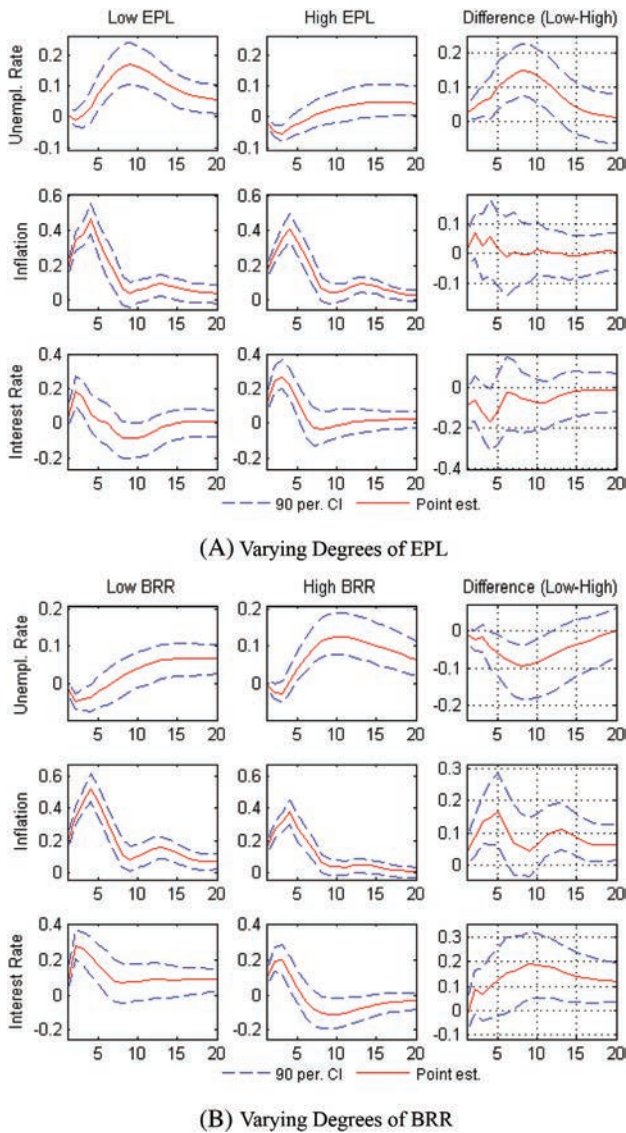
3.1 *Impulse Response Function for Different LMIs*

To assess the role of LMIs, we compare the impulse response functions (IRFs) of the endogenous variables to the two external shocks for different degrees of labor market rigidities. In practice this implies that we compute the IRFs using the estimates in (5), (6), and (7) evaluating all LMIs at their median value, with the exception of the specific LMI of interest, which we vary from taking on the value corresponding to the 20th percentile (low) and 80th percentile (high) of the sample distribution. Figures 1 and 2 present the impulse responses of inflation, unemployment, and interest rates to oil price and world demand shocks for varying degrees of EPL and unemployment benefits. They show three columns: the first depicts IRFs and corresponding 90 percent confidence bands when the relevant LMI has a low level; the second column shows the corresponding IRFs when the LMI has a high level; and the third column shows the difference of the two IRFs. This allows us to assess whether the specific LMI has a significant impact on the dynamic adjustment to the external shocks. The one-standard-deviation shocks roughly correspond to an increase in the oil price by about 15 percent and an increase in world demand by about 0.5 percent on impact.

In line with standard responses to supply and demand shocks, an oil price shock leads to a persistent increase of unemployment, inflation, and interest rates, while an increase in world demand leads to a reduction in unemployment and a (delayed) increase in inflation and interest rates. The size and persistence of the responses, however, differ markedly across different labor market constellations.

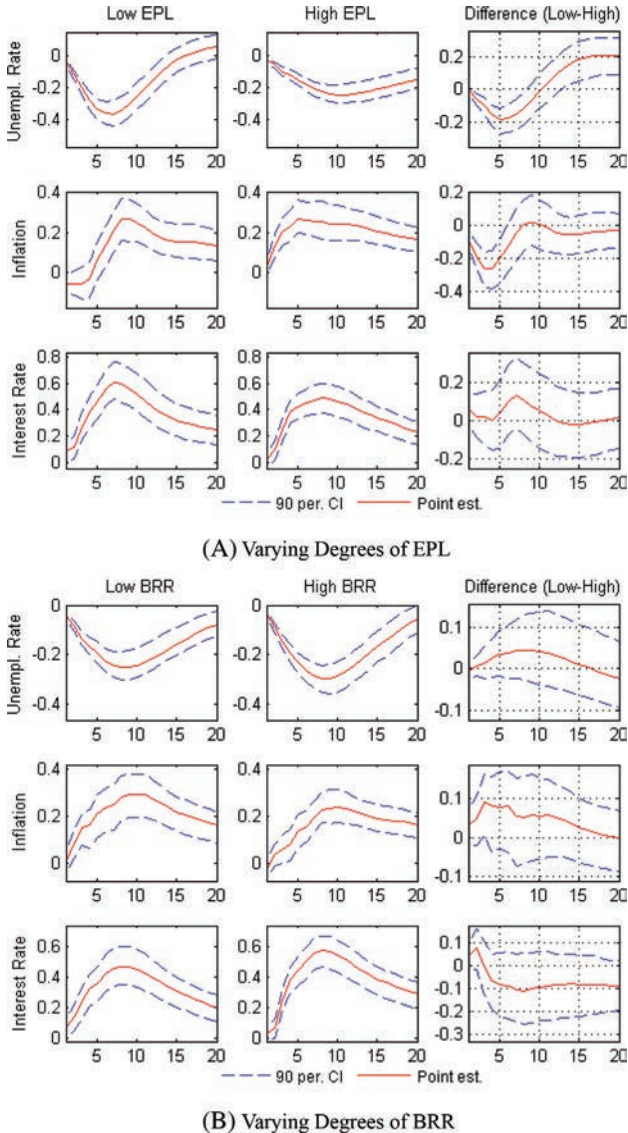
Consider first the effects of the *employment protection legislation index* (EPL), which is generally interpreted as a proxy for firing costs. In theory, firing costs reduce job destruction at given wages during downturns, and also reduce hirings during cyclical

Figure 1. Response to a One-Standard-Deviation Oil Price Shock



Notes: Panels in the first column depict IRFs and corresponding 90 percent confidence bands when the relevant LMI has a low level (20th percentile). Panels in the second column depict IRFs and corresponding 90 percent confidence bands when the relevant LMI has a high level (80th percentile). The third column shows the difference of the two IRFs and the corresponding 90 percent confidence bands.

Figure 2. Response to a One-Standard-Deviation World Demand Shock



Notes: Panels in the first column depict IRFs and corresponding 90 percent confidence bands when the relevant LMI has a low level (20th percentile). Panels in the second column depict IRFs and corresponding 90 percent confidence bands when the relevant LMI has a high level (80th percentile). The third column shows the difference of the two IRFs and the corresponding 90 percent confidence bands.

upswings, because additional employees increase the expected future firing costs. Therefore, when hiring and firing costs are higher, firms find it easier and cheaper to absorb shocks by changing prices than by changing employment. Such an interpretation is in line with Thomas and Zanetti (2009) and Zanetti (2011), who find in a search-and-matching model that higher firing costs dampen the employment adjustment.²⁰ Our empirical results are in line with these models: following the two shocks, higher EPL values lead to a more muted response of the unemployment rate and an amplified response of inflation to the world demand and the oil price shock (figures 1A and 2A). The different dynamics of inflation and unemployment translate into different interest rate responses. Monetary policy largely appears to react proportionally to inflation and unemployment.

A generous *benefit replacement ratio* affects business cycle dynamics through two channels with potentially opposing effects. On the one side, when the unemployment benefit system is very generous, workers face a better outside option and are not willing to accept a big reduction in wages in order to keep their jobs. This implies that wages are less sensitive to aggregate fluctuations while firms' hiring efforts and unemployment are more sensitive (see, e.g., Hagedorn and Manovskii 2008, Campolmi and Faia 2011, and Zanetti 2011). On the other side, unemployment benefits are likely to affect the workers' search effort. In a search model where unemployed workers search with variable intensity or effort, high unemployment benefits may discourage workers from searching. The lower search effort of the unemployed translates into a relatively low job-finding probability and a smaller response of the unemployment rate to shocks. Results from the impulse responses are consistent with the first channel. Higher unemployment benefits reduce the response of the inflation rate and amplify the response of the unemployment rate, although the latter effect is only marginally significant for the world demand shock (figures 1B and 2B). These findings are consistent

²⁰The predictions of search-and-matching models can change depending on the assumption of the productivity level of newly hired workers. Assuming newly hired workers to be less productive than old workers implies that for some calibration values higher firing costs lead to more employment adjustment (Silva and Toledo 2009).

with the view that unemployment benefits induce wage rigidity and amplify unemployment volatilities (see, e.g., Thomas and Zanetti 2009, Campolmi and Faia 2011, and Zanetti 2011).

Table 3 summarizes the results of the impulse response analysis also for the remaining LMIs. It reports the response and significance levels for the inflation and unemployment rates four, eight, and twelve quarters following the two external shocks. Additionally, it reports the quarter in which the difference between the responses of unemployment (inflation) under low and high LMI is at its maximum (last column), the value of unemployment (inflation) in this quarter for low and high LMI (VaPD = value at peak difference), and the associated difference of the unemployment (inflation) response (Peak Dif.).

An institution that has received a lot of attention, especially in Europe, is the *tax wedge*, which is a measure of the difference between labor costs to the employer and the net take-home pay of the employee. Following a supply shock, a higher tax wedge significantly reduces the inflation response but has no significant impact on unemployment dynamics. Similarly, following a demand shock, higher labor taxes are found to significantly reduce inflation volatility but additionally amplify unemployment volatility. These results are consistent with a view of a high tax wedge creating real wage rigidities. A higher tax wedge requires a higher compensation for a given level of consumption, which makes the wage rate less responsive to unemployment changes.

The impact of *unions* on business cycle fluctuations is, in theory, ambiguous. Trade unions are often considered one potential source of real wage rigidities. For instance, Zanetti (2007) introduces union bargaining in a New Keynesian model and finds that unionization lowers inflation volatility but amplifies output volatilities. However, how unions respond to shocks depends primarily on the unions' preferences for tolerating variations in the real wage over variations in the labor force. It is hence perfectly plausible that a powerful trade union may opt for a strategy that allows for higher variations in the wage adjustment as opposed to variations in the labor force. Impulse responses suggest that a higher degree of union density is associated with a stronger response of inflation to shocks, and a somewhat milder variation of the unemployment rate in the case of a world demand shock. Thus, our sample is not supportive of the

Table 3. Impulse Response Peak Difference First Three Years for Varying LMIs

LMI	Variable	Low				High				Peak Dif.	Quarter
		4Q	8Q	12Q	VaPD	4Q	8Q	12Q	VaPD		
Oil Supply Shock											
EPL	Unempl. Rate	0.03	0.16***	0.14**	0.16***	-0.04**	0.02	0.04*	0.02	0.15**	8.00
	Inflation	0.47***	0.06*	0.09**	0.34***	0.41**	0.07*	0.08**	0.27***	0.07*	2.00
BRR	Unempl. Rate	-0.04**	0.02	0.06**	0.02	0.01	0.11**	0.12***	0.11**	-0.10**	8.00
	Inflation	0.52***	0.11***	0.15***	0.44***	0.38**	0.06*	0.05**	0.28***	0.17***	5.00
TW	Unempl. Rate	-0.00	0.07***	0.08***	-0.00	-0.02	0.07**	0.09***	-0.02	0.02	4.00
	Inflation	0.45***	0.11*	0.07*	0.29***	0.43**	0.05*	0.10***	0.20***	0.09*	6.00
UDENS	Unempl. Rate	-0.02	0.08***	0.10***	0.08***	-0.01	0.05**	0.08***	0.05**	0.03	8.00
	Inflation	0.43***	0.04*	0.09***	0.19***	0.46**	0.15**	0.07***	0.33**	-0.14**	6.00
CEW	Unempl. Rate	-0.02	0.05*	0.06*	0.06*	-0.01	0.08**	0.11***	0.11**	-0.05	12.00
	Inflation	0.37***	-0.04	0.01	0.11*	0.47**	0.13**	0.11**	0.31**	-0.20**	6.00
World Demand Shock											
EPL	Unempl. Rate	-0.28***	-0.35***	-0.15***	-0.34***	-0.12**	-0.23**	-0.24**	-0.15**	-0.19**	5.00
	Inflation	-0.03	0.27***	0.19**	-0.03	0.23**	0.26**	0.23**	0.23**	-0.26**	4.00
BRR	Unempl. Rate	-0.17***	-0.25***	-0.22***	-0.25***	-0.19**	-0.30**	-0.25**	-0.30**	0.05*	8.00
	Inflation	0.16***	0.28***	0.27**	0.15***	0.08**	0.23**	0.22**	0.06*	0.09**	3.00
TW	Unempl. Rate	-0.14***	-0.25***	-0.24**	-0.17***	-0.23**	-0.31**	-0.21**	-0.27**	0.11**	5.00
	Inflation	0.17***	0.30***	0.31***	0.33***	0.06*	0.22**	0.20**	0.21**	0.12*	10.00
UDENS	Unempl. Rate	-0.21***	-0.30***	-0.24***	-0.21***	-0.16**	-0.26**	-0.23**	-0.16**	-0.05*	4.00
	Inflation	0.08***	0.23***	0.20***	0.22***	0.16**	0.30**	0.30**	0.32**	-0.10*	10.00
CEW	Unempl. Rate	-0.16***	-0.19***	-0.12**	-0.12***	-0.20**	-0.33**	-0.29**	-0.29**	0.17**	12.00
	Inflation	0.23***	0.36***	0.25***	0.31***	0.05	0.23***	0.24**	0.11**	0.20**	5.00
Notes: VaPD = Value at peak difference, ***, **, and * denote $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively. Significance generally refers to the difference to zero, with the exception of column "Peak Dif.," where significance refers to the difference between the response of the unemployment (inflation) rate for a low compared with a high level of the relevant LMI. Low = 20th percentile and High = 80th percentile of the sample distribution of the relevant LMI.											

view that trade unions create real wage rigidities and reduce inflation volatility. Instead, results support the claim that higher union density may cause a wage-price spiral in response to an external shock and are consistent with earlier univariate results by Bowdler and Nunziata (2007).²¹

The degree of *centralization* of the wage-bargaining process is often used as a proxy for the degree to which trade unions internalize the macroeconomic consequences of their wage claims. Proponents of the corporatist view argue that real wages are more responsive under centralized wage bargaining, because unions internalize possible adverse effects of wage changes on unemployment. Calmfors and Driffill (1988) argue instead that wage setting tends to be less aggressive at the decentralized and at the centralized level, while at intermediate levels wage settlements tend to be higher. This gives rise to the hump-shaped hypothesis. Most studies in the literature find stronger support for the corporatist argument,²² which suggests that the centralization of wage settlement leads to a reduction of real wage rigidities. The results of our estimation following a supply shock are broadly consistent with the corporatist argument. The response of inflation in countries with high centralization is significantly stronger and more persistent than in countries with decentralized wage bargaining. The response of unemployment, instead, is not significantly different in the two cases. However, the effects of the degree of bargaining centralization following a demand shock differ: following a positive world demand shock, countries with centralized wage bargaining are associated with a large, persistent, and significant reduction of the response of inflation but an increase in the unemployment response. One possible explanation for these differences may be related to the fact that while supply shocks imply a tradeoff between inflation and unemployment stabilization for governments and trade unions, such a tradeoff is absent following demand shocks. The optimal strategy of trade unions—and

²¹This interpretation would not apply necessarily to shocks that would trigger a fall in inflation. As this would go well beyond the scope of this paper, we leave an analysis of possible asymmetric effects of LMIs in response to positive and negative shocks to future research.

²²See, for example, Blanchard and Wolfers (2000), Nickell et al. (2001), and Bertola, Blau, and Kahn (2002).

the interactions between unions, governments, and central banks—can thus depend on the type of shocks hitting the economy, and this may explain why it is sometimes difficult to identify the effect of trade unions and of the relevant level of bargaining on business cycle fluctuations.

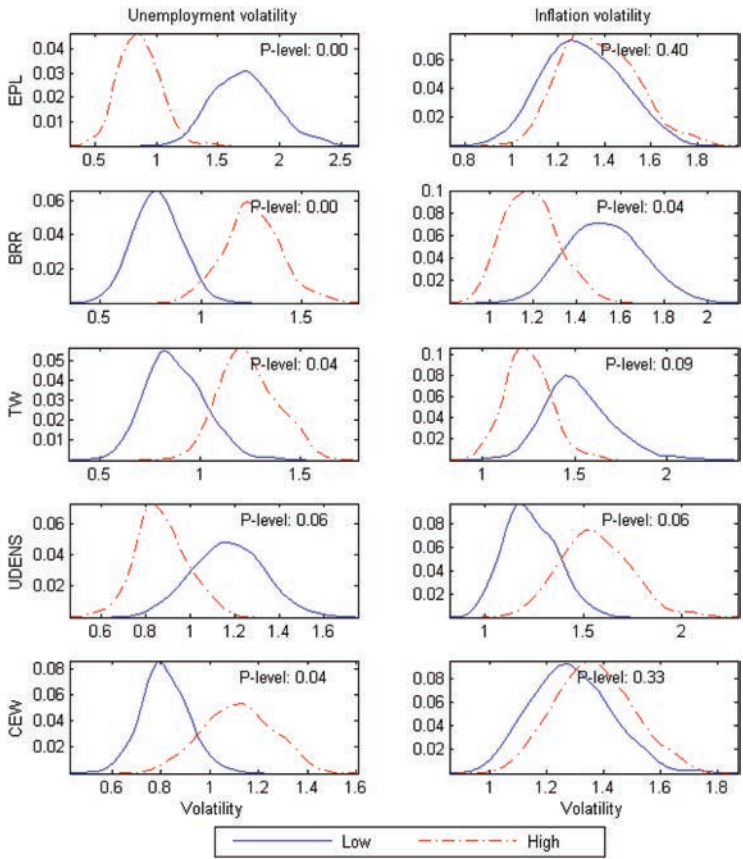
3.2 Inflation and Unemployment Volatility for Different LMIs

To assess the impact of LMIs on macroeconomic volatilities, we use the estimation results to simulate artificial data for different constellations of the labor market and compute the implied variance of the simulated unemployment and inflation series. The exercise is performed considering both external shocks. We vary the LMIs one at a time, evaluating each at the 20th, 50th, and 80th percentile. All other LMIs are set at their median value. For each of these simulated economies, we use the bootstrapped coefficient estimates from regression equations (5), (6), and (7) to account for the coefficient uncertainty when evaluating whether the volatility of inflation and unemployment for different constellations of the labor market are significantly different from each other.

Figure 3 shows how the volatility of unemployment and inflation varies with the value of LMIs. Each panel displays two kernel density estimates of the volatilities' distribution based on the underlying bootstrapped coefficient estimates. One distribution reflects the volatilities obtained when the respective LMI is evaluated at a low value (20th percentile); the other reflects volatilities obtained when the LMI is set at a high value (80th percentile). Additionally, we report for each panel the p-value for the null hypothesis that the means for the low- and high-LMI cases are identical. The left column refers to unemployment volatility, while the right column refers to inflation volatility. The x-axis measures the standard deviation of the simulated variable.

Overall, we find that once we take full advantage of the time dimension of the data and control for the shocks hitting the different economies, most of the LMIs have a large and significant effect on both inflation and unemployment volatilities. Moving from low to high EPL, by restricting the adjustment along the quantity side of the labor market, significantly reduces unemployment volatility by about 52 percent; inflation volatility increases by 5 percent, though

Figure 3. Volatility Density



Notes: Each panel displays two kernel density estimates of the volatilities’ distribution based on the underlying bootstrapped coefficient estimates and obtained varying one LMI while holding all other LMIs at their median value. The solid line reflects the kernel density for the volatilities obtained when the respective LMI is evaluated at a low level (20 percentile); the dotted line reflects the kernel density for the volatilities obtained when the relevant LMI is set at a high value (80th percentile). The p-value is provided for the null hypothesis that the means for the low and high LMI cases are identical.

not significantly so at conventional levels. High unemployment benefits create a form of wage rigidities, and thus increase unemployment volatility by 59 percent and reduce inflation volatility by 25 percent. Both are significant at the 5 percent level. Similarly, moving from

a low to a high tax wedge amplifies unemployment volatility by 18 percent and reduces inflation volatility by 20 percent. Strong unions have the opposite effect: inflation volatility is amplified, but unemployment volatility is lower. Finally, a decentralized wage setting is associated with lower unemployment volatility, but with no significant impact on inflation volatility. This last result can be explained by noticing that the effect of wage-bargaining centralization on inflation volatility following a demand shock is opposite to the effect following an oil price shock. The effects of the two shocks tend to offset each other.

Our results underpin previous findings in the empirical literature. For example, the fact that higher EPL reduces unemployment volatilities corroborates the results of Merkl and Schmitz (2011) and is consistent with the evidence in Faccini and Rosazza Bondibene (2012) and Gnocchi, Laserborg, and Pappa (2015). Similarly, the positive influence of unemployment benefits on unemployment volatility is consistent with the results of Merkl and Schmitz (2011). Regarding inflation volatility, our evidence is in line with Bowdler and Nunziata (2007), who find that higher unionization of the labor force may lead to an amplification of the inflationary effects of macroeconomic shocks. The main difference with previous studies regards the significance and robustness of these results: most of the LMIs are found to have a significant effect on business cycle volatilities, while other studies frequently find support only for a subset of individual LMIs. Moreover, our findings are robust to changes in the sample period and in the countries included in the estimation exercises.²³

Based on their estimated effects on business cycles, LMIs can be divided into two groups: the institutions that lead to employment rigidities—EPL, union density, and a decentralized wage setting—and the ones that tend to reduce the responsiveness of wages and thus create wage rigidities—unemployment benefits and the tax wedge. The first group of institutions limit the adjustment of labor

²³In robustness exercises we estimated the model for two different sample periods (from 1970:Q1 to 1999:Q1 and from 1970:Q1 to 2007:Q1). Moreover, we checked whether results are driven by a single country by excluding one country at a time from the estimation. The main results of the paper are unaffected.

market quantities and shift the adjustment to labor prices; unemployment volatility is reduced while inflation volatility is increased. The second group of institutions reduce the response of labor prices and shift the burden of the adjustment to employment. They, therefore, tend to reduce inflation volatility but increase unemployment volatility. We use this intuition in the following section to study the potential interaction of different LMIs.

3.3 Labor Market Interactions

So far we have varied one LMI at a time to understand their individual effects on the dynamics of inflation and unemployment. Two main results emerge from the previous sections. First, labor market institutions strongly affect business cycle dynamics following external shocks. Second, different types of labor market rigidities have very different, sometimes opposite, effects on inflation and unemployment.

Another question arises naturally from the analysis: how important is the interplay of different labor market institutions? As argued by Bertola and Rogerson (1997), it can be misleading to focus on a unidimensional characterization of labor markets, especially if labor market institutions have counteracting effects on business cycle dynamics. To address this issue, we compare the dynamics of inflation and unemployment in a completely “rigid” labor market economy, where all LMIs take on high values (80th percentile of the sample distribution), with the ones of an economy with completely “flexible” labor markets, where all LMIs take low values (20th percentile of the sample distribution). In our data set, the United States and Switzerland have flexible labor markets, while Belgium is probably the best example of a rigid labor market. We contrast these cases with two artificial economies where LMIs reinforce each other such that the adjustment is predominantly borne out by either labor prices or labor quantities, informed by the results from section 3.2. Specifically, in the first economy EPL and union density are high, while unemployment benefits, the degree of bargaining centralization, and the tax wedge are set at a low level. We label this constellation of the labor market as “quantity rigid,” because these LMIs tend to limit the adjustment of labor quantities and to push

the adjustment to prices. The order is reversed in the second economy, which we label as “price rigid” because in a country with high benefits, high tax wedges, low EPL, low union density, and centralized wage bargaining, it is more costly to change prices, and thus shocks tend to be absorbed through changes in employment. In our data set, the Netherlands is the country that gets closest to the “price rigid” paradigm and Portugal is the one that gets closest to the “quantity rigid” paradigm.

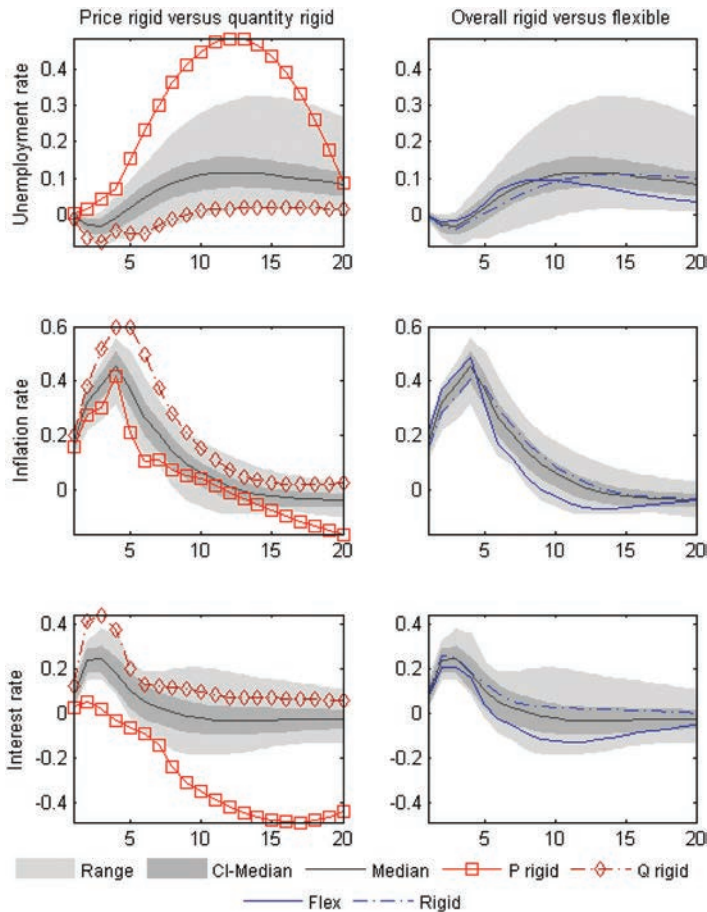
Figure 4 shows the impulse responses of the four hypothetical economies (labeled “Rigid,” “Flex,” “Q rigid,” and “P rigid,” respectively) following an oil price shock. As a benchmark comparison, we also depict the IRFs when all LMIs are evaluated at the median sample value and provide the corresponding 90 percent confidence interval. Moreover, to provide an idea of the impulse responses of specific countries, the light-grey shaded area shows the range that is given by the lowest and highest impulse response based on the average LMI of the individual countries.

Perhaps surprisingly, we find that the dynamics of a completely rigid economy are quite similar to the ones of a completely flexible economy (column 2). In both cases, neither the unemployment response nor the inflation response appear to be significantly different from the benchmark economy in which all LMIs take on the median value.

Looking instead at the “extreme” labor market constellations in column 1, one can observe large differences between “quantity-rigid” and “price-rigid” economies. In a “quantity-rigid” economy, the response of unemployment is fully muted, but the inflation rate sharply increases to 0.6 percent after one year. The corresponding response of the interest rate is relatively mild, with an increase of about 0.4 percent. In a “price-rigid” economy, instead, the unemployment rate increases by 0.5 percentage points after about two years, while the inflation rate peaks at less than 0.4. Consequently the interest rate is initially unchanged and turns even accommodative as the unemployment rate reaches its peak after two years. The results for the world demand shocks are comparable and are depicted in figure 5.

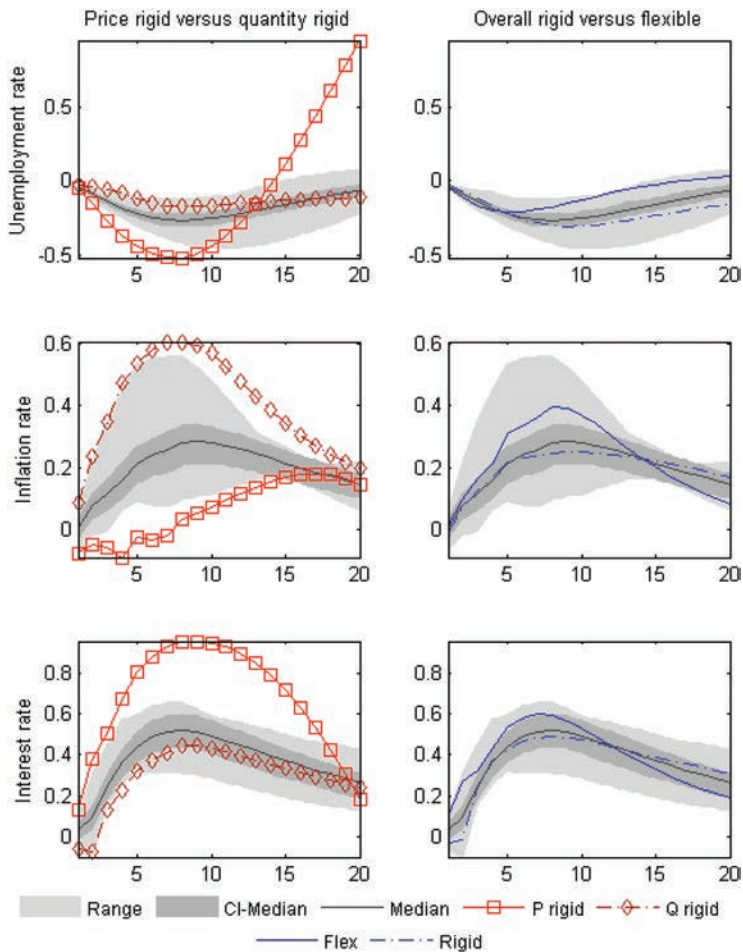
These results suggest that it is crucial to take into account the overall structure of the labor market when drawing policy conclusions.

Figure 4. Response to Oil Price Shock and LMI Interactions



Notes: “Range” refers to the space spanned by the lowest and highest impulse response based on the average LMIs of the individual countries. “CI-Median” refers to the 90 percent confidence interval for the IRF for a hypothetical economy with all LMIs evaluated at the sample median value. “Median” refers to the corresponding median impulse response. “P rigid” refers to the hypothetical economy characterized by an LMI constellation constraining price adjustments, i.e., EPL and UDENS are evaluated at the 20th percentile of the sample distribution and TW, BRR, and CEW are evaluated at the 80th percentile of the sample distribution. “Q rigid” refers to the hypothetical economy characterized by the opposite LMI constellation. “Flex” and “Rigid” refer to hypothetical economies characterized by LMIs corresponding, respectively, to the 20th percentile and to the 80th percentile of the sample distribution.

Figure 5. Response to World Demand Shock and LMI Interactions



Notes: “Range” refers to the space spanned by the lowest and highest impulse response based on the average LMIs of the individual countries. “CI-Median” refers to the 90 percent confidence interval for the IRF for a hypothetical economy with all LMIs evaluated at the sample median value. “Median” refers to the corresponding median impulse response. “P rigid” refers to the hypothetical economy characterized by an LMI constellation constraining price adjustments, i.e., EPL and UDENS are evaluated at the 20th percentile of the sample distribution and TW, BRR, and CEW are evaluated at the 80th percentile of the sample distribution. “Q rigid” refers to the hypothetical economy characterized by the opposite LMI constellation. “Flex” and “Rigid” refer to hypothetical economies characterized by LMIs corresponding, respectively, to the 20th percentile and to the 80th percentile of the sample distribution.

4. Conclusion

The economic consensus view is that “labor market inertia is as crucial as sticky prices in determining macroeconomic shock transmission and adjustment mechanisms” (Bertola 2014). The existing empirical literature, however, finds a limited role of labor market institutions for business cycle dynamics. In this paper we reassessed the link between labor market institutions and inflation and unemployment dynamics using an interacted panel VAR framework that allows coefficient estimates to vary with labor market institutions. Using this approach, we find a significant and sizable effect of several labor market institutions on business cycle fluctuations. Moreover, the results suggest that different labor market rigidities have very different, sometimes opposite, effects on inflation and unemployment. High EPL and high union density, by restricting the adjustment along the quantity side of the labor market, amplify the response of inflation but smooth the response of unemployment. High unemployment benefits and high tax wedges, instead, create a form of real wage rigidities and, therefore, reduce inflation volatility but amplify the unemployment response to shocks. This implies that it can be misleading to draw policy conclusions from unidimensional characterizations of the labor market as rigid or flexible, because the dynamics in countries with overall rigid labor markets are not found to be significantly different from the dynamics in economies with flexible labor markets. The starkest contrast in the responses of inflation and unemployment to shocks can be found in those countries with institutions that limit price adjustments relative to those countries with institutions that limit quantity adjustments.

The findings of this study have relevant implications, for instance, in the context of a monetary union.²⁴ When countries within a union exhibit heterogeneous labor markets, the propagation of shocks differs across member states. Symmetric shocks (and thus monetary policy) may have strong asymmetric effects and lead

²⁴See, e.g., Abbritti and Mueller (2013) and Faia, Lechthaler, and Merkl (2014). Faia, Lechthaler, and Merkl (2014) study optimal monetary policy in a model with turnover costs and show that the inefficiencies of the competitive economy increase with the magnitude of firing costs. Abbritti and Mueller (2013) set up a dynamic currency union model and show that asymmetries in labor market structures worsen the adjustment of a currency union to shocks.

to inefficient inflation and unemployment differentials. Whether this calls for a coordination of labor market reforms, however, depends on the exact configuration of the labor markets of member countries. In particular, the differences in the adjustment mechanisms to shocks may not be as pronounced as expected, because labor market institutions can have opposing effects on business cycle dynamics. Considerations about equilibrium unemployment rates and social preferences, not discussed in this paper but often considered of overriding importance, may in such cases outweigh the benefits for monetary policy coming from a harmonization of labor market structures.

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External Appendix - Reassessing the Role of Labor Market Institutions for the Business Cycle

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This version: March 2016.

1 Data

The following section describes in detail how the five labor market indicators from the original CEP-OECD institutions database by Nickell (2006), employed in this study, are extended beyond 2003, when the original database ends.

Data extension

The labor market indicators from the CEP-OECD institutions database are extended using the following adjustments for the respective series:

Union density (percent)

Union density (UDENS) is fully replaced by the ICTWSS source file data. The series covers all countries and extends until 2013. For some countries, where data is only available until 2012, values are held constant in 2013. The correlation between the CEP-OECD data and the updated data is 0.99 for 623 overlapping observations.

Benefit replacement rate (percent)

The measure for the unemployment benefit generosity (BRR) is fully replaced with the OECD source file. From 1970 to 2005 the gross replacement rate (GRR) of the average production worker (APW), which is also used in the CEP-OECD institutions database, is available. Thereafter, the available data relies on the new OECD measure for GRR, which is constructed in a similar way as the GRR (APW) series, but is calibrated to the average worker (AW). Differences for overlapping periods are very limited with the exception of Italy. The value for Italy after 2005 is, therefore, constructed by adding the change in the GRR (AW) to the lagged GRR (APW) in the previous period. The bi-annual data extends until 2011 (covering uneven years). Values after 2011 are kept constant until 2013. Even years are interpolated. The correlation between the CEP-OECD data and the updated OECD data is 0.99 for 680 overlapping observations.

Employment protection legislation (index)

The employment protection legislation index (EPL) is (recursively) extended using the following formula:

$$EPL_t = EPL_{t-1} + \Delta \widehat{EPL}_t \quad (1)$$

where Δ refers to the first difference operator and $\widehat{EPL}_t = c_1 + \beta_1 EPL_t^{OECD}$ corresponds to fitted values from an OLS regression of the CEP-OECD EPL indicator on the OECD EPL indicator for individual and collective dismissals and on a constant c_1 . The OECD EPL indicator for individual and collective dismissals refers to regular contracts, version 1, and is available from 1985 to 2013. A higher value indicates stricter employment protection legislation. The correlation between the CEP-OECD EPL and the OECD EPL indicator is 0.86 for 280 overlapping observations.

Centralization of wage bargaining (index)

The index of wage bargaining centralization (CEW) is extended using a reclassified version of the ICTWSS indicator for the level at which bargaining takes place (LEVEL). The CEP-OECD data (based on Ochel 2000, 2001) classifies the bargaining level according to three levels:¹

- 1 = Company/Plant level
- 2 = Sectoral level
- 3 = Central level

The ICTWSS instead uses five levels:

- 1 = bargaining predominantly takes place at the local or company level
- 2 = intermediate or alternating between sector and company bargaining
- 3 = bargaining predominantly takes place at the sector or industry level
- 4 = intermediate or alternating between central and industry bargaining
- 5 = bargaining predominantly takes place at central or cross-industry level

¹The CEW(INT) series is the interpolated version of the CEW indicator in the original dataset. The latter is constant for 5-years, while the former models a smoother transition between changes to the wage bargaining set-up and takes on non-integer values between 1 and 3.

The reclassification is given by the following rules for converting the ICTWSS into the CEW(INT) scale:

5	—>	3
4	—>	2.5
3	—>	2
2	—>	1.5
1	—>	1

The correlation between the CEP-OECD CEW(INT) and the ICTWSS rescaled LEVEL indicator is 0.77 for 605 overlapping observations. For the years that the original CEW(INT) is not available the reclassified ICTWSS is used. The resulting series is smoothed using a locally weighted regression with running-mean smoothing and a narrow bandwidth of 0.2. This leaves the period of the original dataset essentially unaltered (with a correlation of 0.997), but imposes the same interpolation pattern of the original CEW(INT) measure of the CEP-OECD database in the transition to and the period covered by the rescaled ICTWSS measure.

Tax wedge (percent)

The tax wedge (TW) is extended drawing on multiple sources, because no single source has data available for a large enough sample. The original CEP-OECD database comprises two TW measures: a tax wedge measure based on OECD data (TW) and a measure based on the Nicoletti institutions data (TW^{NICOL}). The CEP-OECD tax wedge measure TW defines the tax wedge as the sum of the employment tax rate, the direct tax rate and the indirect tax rate.² The TW^{NICOL} measure defines the tax wedge as the ratio of employers' and employees' social security contributions and income taxes over total labour costs (gross wage + employers' social security contributions).³ The two series, which are highly correlated, are extended using data from the OECD National Accounts and Revenue Statistics databases.

The updating of the original CEP-OECD tax wedge proceeds in steps, exploiting first the most relevant information and then moving to the second most relevant information for the

²See, e.g., Nickell (2006) for details.

³See, e.g., Nicoletti et al. (2001).

remaining missing data, and then to the third and so on. The main steps are: First, the CEP-OECD indicator TW is extended using OECD source data. Second, the indicator TW^{NICOL} is extended drawing also on the relevant OECD source data. In a final step the two extended series are combined to derive the longest possible series for the tax wedge.

First step: TW is (recursively) extended using the following formula:

$$TW_t = TW_{t-1} + \Delta \widehat{TW}_t \quad (2)$$

where Δ refers to the first difference operator and $\widehat{TW}_t = c_2 + \beta_2 TW_t^{comp}$ corresponds to fitted values from an OLS regression of the original CEP-OECD indicator of TW on the updated computation using OECD source data in line with the description in the CEP-OECD database manual. The correlation between the CEP-OECD TW and the computed TW^{comp} based on OECD source data is 0.97 for 228 overlapping observations. The following countries can be extended by this approach (in line with data availability for the underlying OECD source data): Australia (1986-2012), Austria (2004-2013), Belgium (2004-2013), Canada (2001-2013), Denmark (2003-2013), Finland (2004-2013), France (2004-2013), Germany (2004-2013), Italy (2004-2013), Netherlands (2004-2012), Norway (2003-2013), Portugal (2003-2013), Spain (2004-2013), Sweden (2003-2013), United Kingdom (2001-2013), and United States (2004-2013).

Second step: TW^{NICOL} is (recursively) extended using the following formula:

$$TW_t^{NICOL} = TW_{t-1}^{NICOL} + \Delta \widehat{TW}_t^{NICOL} \quad (3)$$

where Δ refers to the first difference operator and $\widehat{TW}_t^{NICOL} = c_3 + \beta_3 TW_t^{NICOLcomp}$ corresponds to fitted values from an OLS regression of the original CEP-OECD indicator TW^{NICOL} on the updated computation using OECD source data in line with the description in Nicoletti et al. (2001). The correlation between the CEP-OECD TW^{NICOL} and the computed $TW^{NICOLcomp}$ based on OECD source data is 0.95 for 189 overlapping observations. The following remaining countries can be extended by this approach (in line with data availability for the underlying OECD source data): Ireland (1990-1998), Japan (2003-2012), New Zealand

(1999-2013), and Switzerland (1991-2013).⁴

Third step: Combine the information from the extended TW series and the extended TW^{NICOL} series using (recursively) the following formula:

$$TW_t = TW_{t-1} + \Delta \widehat{TW}_t^{NICOL}, \text{ if } TW_{t-1} \text{ is available and} \quad (4)$$

$$TW_t = c_4 + \beta_4 \widehat{TW}_t^{NICOL} \text{ otherwise.} \quad (5)$$

The latter case is only relevant for New Zealand (1972-2013), and Ireland (1999-2013). The correlation of the updated TW^{NICOL} indicator and the updated TW is 0.83 for 801 overlapping observations.⁵ The charts below provide an overview by country.

⁴Because 2013 data is missing for three countries (Australia, Japan, and Netherlands), we also make use of the first principal component of the tax wedge data for all income levels and household compositions from the OECD taxing wages calculator, for these observations. This data is available starting in 2000. The correlation between the extended TW^{NICOL} and the principal component based on OECD source data is 0.84 for 277 overlapping observations.

⁵The results of the paper are unaffected when using the slightly shorter sample employing either the extended tax wedge measure based on OECD data (TW) or the extended tax wedge measure based on the Nicoletti institutions data (TW^{NICOL}), i.e. dropping step 3 and using the separate measures individually.

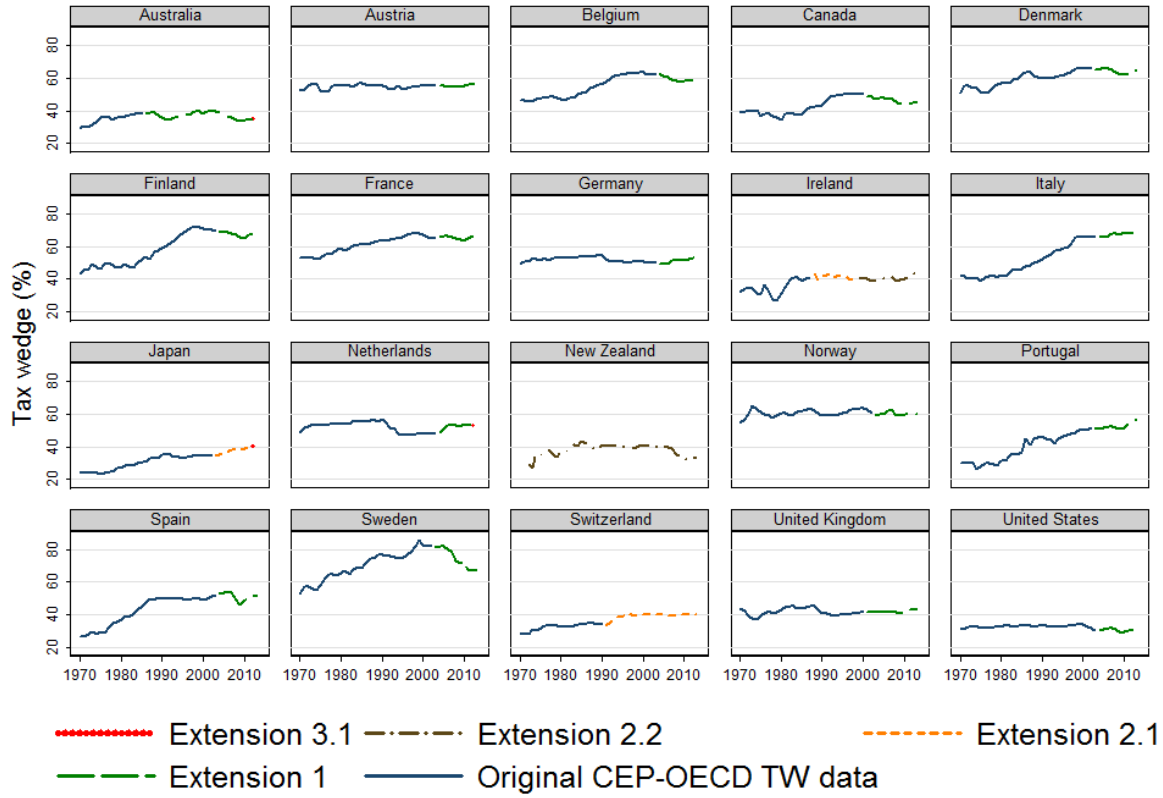


Figure 1: Tax wedge

Note: The respective extensions refer to: Extension 1: TW updated series based on OECD source data, Extension 2.1: based on original Nicoletti et al. (2001) data and recursive extension using OECD source data, Extension 2.2: based on non-recursive extension of Nicoletti et al. (2001) data using OECD source data, Extension 3.1: based on original Nicoletti et al. (2001) data and recursive extension using principal component of indicators from OECD.

2 Volatility Regression

In this section, we estimate directly the relationship between labor market institutions and the volatilities of inflation and the unemployment rate, similar to earlier approaches in the literature (see for instance Rumler and Scharler (2011), Merkl and Schmitz (2011)). We measure the volatility of a variable by the standard deviation of its HP filtered cyclical component. In line with much of the empirical literature on the macroeconomic effects of LMIs, the volatility measure is computed for 9 non-overlapping 5-year periods, roughly equivalent to the average length of the business cycle.⁶ This procedure results in a panel with potentially 180 observations, but the effective sample is slightly shorter given missing LMIs and interest rate data for some countries in the earlier periods. Our baseline OLS regression is given by:

$$\ln \sigma_{i,t} = \beta \Lambda_{i,t} + \gamma X_{i,t} + e_{i,t} \quad (6)$$

where $\ln \sigma_{i,t}$ stands for the log of the standard deviation of the dependent variable (inflation or unemployment rate) for country i and period t and $\Lambda_{i,t}$ for the labor market indicators. $X_{i,t}$ is a vector of controls potentially including a constant, time fixed effects, country fixed effects, the (log) volatility of output (σ_Y) and the monetary policy stance proxied by the average real interest rate (R). Labor market variables are scaled such that coefficient estimates are interpretable as the percentage change in the standard deviation of the dependent variable as a response to a one unit change in the independent variable. The coefficient on the monetary policy stance is the semi-elasticity of the standard deviation of inflation and unemployment with respect to a 1 percentage point increase in the real interest rate. Standard errors are bootstrapped. Table 1 shows the results for the volatility of inflation and Table 2 for the volatility of the unemployment rate.

Based on the various regression results (A1-A8), we find no robust relationship between the labor market indicators and the volatility of inflation. While several indicators are significant at times (in particular unemployment benefits, the tax wedge, and the union density measures), coefficients change sign, are insignificant, or are not robust to the inclusion of country fixed

⁶Only the most recent period is limited to a shorter sample as data for 2014 and 2015 on LMIs are not yet available.

effects. Only union density appears to increase the volatility of inflation in almost all regressions (A1-A7), but turns insignificant when including all the controls. The only robust relationships that hold are that countries with higher output volatility tend to have higher inflation volatility and countries with tighter monetary policy lower inflation volatility.

A similar picture emerges for the effects of labor market indicators on the volatility of unemployment (Table 2). Throughout the regressions, the only variable that is always significant is output volatility. Employment protection legislation (EPL) is significant in two regressions (B3 and B6) notwithstanding the inclusion of time fixed effects and controlling for the overall output volatility and the monetary policy stance. However, the inclusion of country fixed effects generally implies that EPL is not significant anymore.⁷ Similarly, unemployment benefits are significant in three regressions, but turn insignificant when including country fixed effects and the controls for monetary policy. The coefficients on the tax wedge and the degree of centralization are often insignificant and change sign with the specification.

Overall, these results point towards a rather weak effect of LMIs on macroeconomic fluctuations. This evidence contradicts economic theory and conventional wisdom, but is broadly consistent with many other studies that follow a similar approach and find a limited effect of most labor market institutions on unemployment and inflation dynamics.

⁷However, the Hausman test cannot reject that there is no systematic difference between random and fixed effect models.

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	Dependent Variable: $\text{Ln}(\sigma_\pi)$							
	(A1)	(A2)	(A3)	(A4)	(A5)	(A6)	(A7)	(A8)
EPL	22.6 (21.2)	2.4 (32.7)	8.8 (7.9)	28.5 (17.6)	44.3 (33.4)	8.6 (8.9)	-1.0 (42.0)	3.0 (38.4)
BRR	-0.7 (0.5)	-0.6 (0.8)	-0.5 (0.4)	-0.9* (0.5)	-0.9 (0.7)	-0.6 (0.4)	-0.5 (0.7)	-0.8 (0.6)
TW	-2.8*** (0.7)	-2.7*** (0.9)	-1.9*** (0.3)	-2.1*** (0.6)	-1.4 (1.0)	-1.3*** (0.3)	-0.4 (1.0)	0.1 (0.9)
UDENS	1.6*** (0.4)	2.5*** (0.6)	1.1*** (0.2)	1.2*** (0.4)	2.0*** (0.5)	0.7*** (0.2)	1.4* (0.8)	0.5 (0.7)
CEW	9.4 (11.4)	4.0 (16.9)	7.0 (6.7)	3.5 (13.3)	-3.2 (15.6)	5.8 (7.8)	-1.4 (15.1)	-3.0 (14.3)
R				-3.4*** (1.1)	-4.4*** (1.5)	-1.7 (3.6)		-6.3* (3.5)
σ_Y				52.8*** (9.6)	55.1*** (7.7)	42.1*** (8.0)		44.0*** (12.1)
Constant	57.2** (23.2)	40.1 (71.9)	41.4*** (14.7)	42.2* (25.4)	-12.2 (66.2)	29.1* (15.1)	-14.9 (69.0)	-9.4 (62.1)
Observations	176	176	176	172	172	172	176	172
R^2 (within)		0.30	0.19		0.49	0.30	0.57	0.64
Countries	20	20	20	20	20	20	20	20
Periods	9	9	9	9	9	9	9	9
Time FE	No	No	Yes	No	No	Yes	Yes	Yes
Country FE	No	Yes	No	No	Yes	No	Yes	Yes
R^2 (overall)	0.32	0.28	0.32	0.45	0.38	0.45	0.46	0.55
Hausman		0.40	0.06		0.09	0.64		

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 1: Regression for Inflation

	Dependent Variable: $\text{Ln}(\sigma_{UR})$							
	(B1)	(B2)	(B3)	(B4)	(B5)	(B6)	(B7)	(B8)
EPL	-9.6 (31.8)	21.5 (33.9)	-39.1*** (11.0)	-8.6 (31.1)	21.5 (51.5)	-24.5** (10.5)	-36.3 (54.1)	9.8 (46.3)
BRR	1.7** (0.7)	1.4 (0.9)	1.4*** (0.4)	1.2 (0.9)	1.0 (1.2)	1.3*** (0.4)	1.2 (1.0)	1.0 (1.1)
TW	0.4 (0.9)	1.4 (0.9)	-0.5* (0.3)	1.3 (0.9)	2.2** (1.0)	0.1 (0.4)	0.6 (1.4)	1.1 (1.5)
UDENS	0.2 (0.5)	0.5 (0.7)	0.2 (0.2)	-0.4 (0.5)	-0.2 (0.6)	-0.3* (0.2)	0.1 (1.1)	0.2 (1.1)
CEW	-8.2 (13.8)	-11.7 (12.6)	21.0*** (6.0)	-12.9 (14.9)	-18.8 (12.1)	11.3*** (4.3)	-4.4 (13.2)	-10.5 (11.7)
R				4.1*** (1.4)	3.3** (1.6)	3.2 (3.8)		1.7 (2.5)
σ_Y				56.4*** (8.0)	57.2*** (8.0)	56.7*** (9.3)		56.7*** (9.8)
Constant	-125.3*** (41.9)	-193.5*** (59.1)	-110.6*** (12.2)	-147.2*** (39.6)	-204.5*** (79.3)	-128.9*** (16.0)	-151.3** (75.1)	-221.7*** (76.5)
Observations	177	177	177	172	172	172	177	172
R ² (within)		0.11	0.14		0.37	0.25	0.34	0.50
Countries	20	20	20	20	20	20	20	20
Periods	9	9	9	9	9	9	9	9
Time FE	No	No	Yes	No	No	Yes	Yes	Yes
Country FE	No	Yes	No	No	Yes	No	Yes	Yes
R ² (overall)	0.09	0.04	0.10	0.28	0.19	0.29	0.26	0.35
Hausman		0.41	0.01		0.65	0.01		

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2: Regression for Unemployment Rate

Inflation Volatility							
	20^{th}	50^{th}	80^{th}	(ln) difference	A1-A8		
				$80^{th} - 20^{th}$	Average	Min	Max
EPL	1.31	1.31	1.38	5%	9%	-0.6%	28%
BRR	1.53	1.31	1.19	-25%**	-11%	-14%	-8%
TW	1.52	1.31	1.25	-20%*	-35%	-64%	-2%
UDENS	1.2	1.31	1.56	26%**	40%	14%	73%
CEW	1.28	1.31	1.37	6%	3%	-3%	10%

Unemployment Volatility							
	20^{th}	50^{th}	80^{th}	(log) difference	B1-B8		
				$80^{th} - 20^{th}$	Average	Min	Max
EPL	1.63	1.03	0.96	-52%***	-5%	-25%	14%
BRR	0.77	1.03	1.39	59%***	21%	16%	27%
TW	0.99	1.03	1.18	18%**	19%	-11%	50%
UDENS	1.21	1.03	0.96	-23%*	1%	-12%	15%
CEW	0.88	1.03	1.16	28%**	-5%	-20%	22%

Using external shocks only							

Table 3: Volatility as a function of LMIs

Tail Co-movement in Inflation Expectations as an Indicator of Anchoring*

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We analyze the degree of anchoring of inflation expectations in the euro area during the post-crisis period, with a focus on the time span from 2014 onwards when long-term beliefs have substantially drifted away from the policy target. Using a new estimation technique, we look at tail co-movements between short- and long-term distributions of inflation expectations, estimated from daily quotes of inflation derivatives. We find that, during 2014, average correlations between short- and long-term inflation expectations rose sharply; moreover, negative tail events impacting short-term beliefs have been increasingly channeled to long-term views, triggering both downward revisions in expectations and upward changes in uncertainty. Overall, our results signal a risk of downside de-anchoring of long-term inflation expectations.

JEL Codes: C14, C58, E31, E44, G13.

1. Introduction

Headline inflation in the euro area has been falling since 2012 and became negative at the end of 2014. The five-year, five-year forward (5y5y forward) inflation swap rate, a commonly used indicator of medium- to long-term inflation expectations, has fallen well below

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2 percent since September 2014; on September 4, the phrase *inflation expectations for the euro area over the medium to long term continue to be firmly anchored* was abandoned for the first time in the monetary policy statements of the European Central Bank. Inflation expectations persistently below the 2 percent level may suggest a loss of confidence in the ability of the monetary authority to achieve its inflation target; if inflation expectations are de-anchored, then consumption and investment could be postponed, leading to a deflationary spiral.

In this paper we analyze whether there has been a downside de-anchoring of long-term inflation expectations in the euro area after the global financial crisis. We propose a new method of assessing the degree of anchoring of expectations that overcomes weaknesses in standard techniques used to measure the *pass-through* of expectations. Looking at a set of indicators that includes the co-movement between extreme changes in long- and short-term market-based inflation expectations, we find that signs of downside de-anchoring have emerged in 2014.

Ordinary pass-through models of inflation expectations assume that when expectations are firmly anchored to the central bank's target, long-term expectations should be quite stable, not reacting (as short-term expectations do) to inflation or macro data releases; according to this claim, linear correlations of long-term expectations with short-term expectations provide insights on the sensitivity of long-term beliefs and might reveal possible signs of de-anchoring. However, linear correlations may not be sufficient to assess the degree of anchoring for two main reasons: first of all, they measure average correlations while, in times of falling expectations and interest rates close to the zero lower bound, concomitant downswings in short- and long-term expectations could be more informative than concomitant upswings to identify a de-anchoring below the target; secondly, they disregard the pass-through of uncertainty and, in general, variations in the entire distribution of long-term expectations.¹

¹Even when long-term expectations are relatively stable, the uncertainty around these expectations might be significantly volatile. In light of that, as pointed out by many authors, inflation targeting should help anchor market perceptions of the *entire* distribution of long-term expectations (e.g., Gürkaynak, Levin, and Swanson 2010).

On the grounds of the aforementioned elements, we investigate possible signs of de-anchoring by estimating the co-movement between changes in breakeven inflation (proxying risk-neutral inflation expectations) as well as between variations in the dispersion around these prices, at different maturities.

The whole investigation relies on inflation swaps and options (caps and floors). Without further identification assumptions, estimates based on their market quotes jointly represent inflation expectations and the inflation risk premium attached to them: while inflation risk premia are also informative, as well as expectations, in assessing the degree of anchoring, we choose not to extract risk premia and to loosely refer to breakeven inflation as inflation expectations throughout the analysis.²

The analysis is carried out in two steps: in the first one, we derive the option-implied probability distributions of future inflation one, two, three, five, seven, and ten years ahead on a daily basis in the period between October 2009 and February 2015 using the semi-nonparametric technique of Taboga (2016); secondly, we evaluate the co-movement between short- and long-term expectations and standard deviations using (i) linear correlations and (ii) tail correlations (i.e., correlations between extreme variations in short- and long-term expectations or long- and short-term standard deviations) based on the theory of copulas and on the TailCor estimator of Ricci and Veredas (2013).

We find that, during 2014, the co-movement between the short- and long-term distributions of expected inflation was asymmetric: on the one hand, long-term expectations reacted more to downswings than to upswings in short-term ones; on the other hand, the standard deviation of the distribution of long-term expectations reacted more to increases than to decreases in short-term uncertainty. This joint evidence suggests that signs of de-anchoring have emerged.

A growing literature investigating anchoring in the most recent period is reporting mixed results. Strohsal and Winkelmann (2015) find more firmly anchored inflation expectations in the euro area than in the United States as of 2011; moreover, estimates based on inflation swaps and options suggest only mild reactions of inflation

²A discussion of the role of risk premia in market-based estimates is provided in section 2.2.

beliefs to macroeconomic announcements during the crisis (Autrup and Grothe 2014) and post-crisis period (Scharnagl and Stapf 2015 and Speck 2016). Our result is in line with Ehrmann (2014), who studies the stability of long-term beliefs in a panel of countries before and after inflation targeting: under persistently low inflation, he finds that a sign of downside de-anchoring with respect to a target is that inflation expectations get revised down in response to lower-than-expected inflation but do not respond to higher-than-expected outturns. Our result is also coherent with the findings in Lyziak and Paloviita (2016) such that longer-term inflation forecasts have become somewhat more sensitive to shorter-term forecasts and to actual HICP inflation.

The most common method used to assess the degree of anchoring in one economy involves testing the sensitivity of inflation expectations to surprises in macro news (the *news-regression* approach of Gürkaynak, Sack, and Swanson 2005). While news regressions heavily depend on how the surprise component of each announcement is estimated, our approach is totally market based, so it is free from identification issues.³ In addition to the newly designed technique to evaluating anchoring, we also contribute to the option literature by providing robust estimates of euro-area inflation densities and by applying copula-based and TailCor methods to option-implied data.

This paper is organized as follows. In section 2, we describe the data set of inflation swaps and options on euro-area inflation (section 2.1) and the derivation of option-implied distributions of future inflation (section 2.2). Section 3 presents the measures employed to assess the degree of anchoring (section 3.1) and describes the building blocks of the empirical analysis (section 3.2). In section 4 we present the estimates of the option-implied distributions of inflation and discuss the evolution of deflation probabilities, quantiles, means, standard deviations, and skewness for the available maturities (section 4.1); the measures of anchoring are computed on inflation swaps and standard deviations of the estimated distributions and results are discussed in section 4.2. Section 5 concludes.

³The link between tail co-movements and anchoring is first investigated in Antunes (2015), where coefficients of tail dependence between daily revisions of short- and long-term inflation swaps are constructed using different types of bivariate copulas.

2. Option-Implied Distributions of Future Inflation

2.1 *Swaps and Options on Euro-Area Inflation*

The market for inflation-linked derivatives has witnessed a considerable development in the past few years. The most popular inflation derivatives include inflation swaps and inflation options (caps and floors). An inflation swap is a derivative contract in which two parties agree to exchange a fixed amount of money with a floating amount linked to realized inflation on particular dates in the future. An inflation cap is a derivative contract in which the holder has the right to receive compensation payments at the end of each period in which the inflation rate exceeds an agreed-upon strike rate. The contract involves no obligations when the realized inflation is below the strike. In exchange for the contingent future payment, the holder pays a price (option premium) upfront. A floor is a derivative contract that gives the holder the right to receive payments at the end of each period in which the inflation rate falls below the predetermined strike. Inflation swaps, caps, and floors can be zero coupon or year-on-year. Zero-coupon contracts consist of a single compensation payment at maturity, while year-on-year ones include intermediate payments depending on the level of the inflation rate in each year of the reference period.

The underlying of quoted swaps and options is euro-area HICPxT, lagged by three months in order to be known at the maturity date of the option.⁴ Bloomberg provides quotes for both zero-coupon and year-on-year swaps and options on euro-area inflation; for our purpose, we only rely on prices of zero-coupon contracts between October 2009 and February 2015.

The degree of liquidity of caps and floors is not easy to assess; according to Smith (2012), euro-area inflation option markets are more liquid than the U.K. and U.S. ones. Scharnagl and Stapf (2015), whose analysis is also based on zero-coupon options, check for their degree of liquidity by calculating put-call parities and show that no arbitrage violations arise for at-the-money options. In addition, it is worth mentioning that we adopt an estimation methodology (based

⁴Since the HICPxT is not observed daily, the fixed leg of an inflation swap contract over the same horizon, which is traded daily, is taken as a proxy.

on Taboga 2016) that is robust to outliers: pricing errors due to low liquidity should not have a significant impact on the results.

2.2 Extraction of Option-Implied Probability Distributions

The extraction of risk-neutral probability distributions from option quotes is based on the semi-nonparametric method developed in Taboga (2016). In what follows we briefly describe the estimation methodology; see appendix 1 for a more detailed description. The probability distribution of future inflation is assumed to have a discrete support;⁵ then, in the absence of arbitrage opportunities there exists a finite set of positive state prices such that the price of any derivative contract on inflation can be expressed as a function of those state prices. Risk-neutral distributions can be simply obtained by rescaling once state prices are estimated. The method assumes that state prices are interpolated by a spline function, which is proved to be equivalent to a set of linear restrictions. The linearity of the problem allows for the derivation of computationally inexpensive estimators. In particular, a least absolute deviations (LAD) estimator can be obtained through a linear programming problem. In addition, this methodology allows for the incorporation of unimodality restrictions on the estimators of state prices. Unimodality of risk-neutral distributions obtained from state prices is a desirable property, and in the previous literature it was not dealt with.⁶

In addition to the computational convenience, the advantages of this methodology include its robustness to outliers, which are known to contaminate data on option prices. Despite the lack of information on the liquidity of option quotes, the robustness of the methodology supports confidence in the estimated state prices.

Throughout the paper, we need to bear in mind that probability distributions extracted from option quotes are risk neutral by assumption, i.e., they are not adjusted for investors' risk preferences.

⁵Assuming that the probability distribution of future inflation is discrete does not reduce significantly the scope of the methodology; in fact, continuous distributions can be arbitrarily approximated by discrete ones; moreover, most pricing algorithms require discretization at some stage; finally, market prices are inherently discrete.

⁶As explained in Taboga (2016), multimodality is often an artifact due to estimation procedures rather than an authentic feature of the data.

Risk-neutral distributions incorporate an inflation risk premium in addition to the expectation of future inflation, as well as a liquidity premium. Concerning the inflation risk premium, term structure estimates show that risk premia are significantly volatile, especially on long maturities.

However, inflation risk premia, whose identification gave mixed results in the literature in terms of magnitude and sign, are informative, as well as expectations, in assessing the degree of anchoring: indeed, the investors' willingness to pay large premia in order to protect themselves against a scenario of persistently low inflation would also signal high risks in terms of the central bank's credibility and ability to bring inflation back to target.⁷ Bauer and Christensen (2014) point out that risk-neutral probabilities are useful for policy analysis, as policymakers are worried about extreme outcomes just like investors. As stated by Kocherlakota (2013), policy decisionmaking should take into account the evolution of risk-neutral probabilities, since it reflects changes in market participants' views about future possible outcomes.

For these reasons, we choose to not extract risk premia and consider breakeven inflation (and their probability distributions) throughout the analysis, loosely referring to those as inflation expectations.

3. Co-movement between Short- and Long-Term Moments

3.1 Measures of Average and Tail Co-movement

The co-movement between two random variables can be studied in various ways. One standard measure is the Pearson correlation, which estimates the average level of co-dependence. There are some important limits of such a measure: first of all, it does not take into account non-linear relationships between variables; secondly, it does not distinguish between different types of variations (large and

⁷The heterogeneity of the available estimates of inflation risk premia is highlighted also by Pericoli (2012), who provides a comparison of some estimates found in the literature and shows that there indeed are stark differences among them.

small, positive and negative), which are relevant in our assessment of de-anchoring.

In order to detect the co-dependence between extreme variations in short- and long-term expectations, we then turn to two different indicators of tail co-movement: the coefficient of conditional tail dependence, estimated through copulas, and the TailCor index.

3.1.1 Coefficient of Conditional Tail Dependence

The coefficients of conditional upper and lower tail dependence are defined as follows:⁸

DEFINITION 1. *Let X and Y be two random variables with marginal distributions $F_X(x)$ and $F_Y(y)$. Let x_k denote the k -th quantile of variable X and let y_k be the k -th quantile for Y . The conditional upper tail dependence is defined as*

$$\lambda_U = \lim_{k \rightarrow 1} \Pr\{Y > y_k | X > x_k\};$$

the conditional lower tail dependence is defined as

$$\lambda_L = \lim_{k \rightarrow 0} \Pr\{Y \leq y_k | X \leq x_k\}.$$

Intuitively, λ_U measures the asymptotic probability of having large outcomes in variable Y , conditional on observed large realizations for variable X . One way to compute the coefficients of conditional tail dependence is through copulas; copula functions are a special class of multivariate cumulative distribution functions that allow for separating the modeling of the marginal distributions from the dependence structure between the variables.⁹ The advantage of using this approach is that for some choices of copula functions, the coefficient of conditional tail dependence can be retrieved in closed form.

⁸The coefficient of tail dependence was first introduced in the finance literature by Embrechts, Lindskog, and McNeil (2003).

⁹See appendix 2 for copula definition and main properties, and Nelsen (2006) for a detailed exposition of the theory and practical aspects of copulas.

Estimating the coefficients of conditional tail dependence through copulas involves (i) choosing the appropriate copula function; (ii) estimating the parameters that maximize the fit of the chosen copula to the data; and (iii) computing the coefficient of tail dependence as a function of the estimated parameters using the closed-form expression.

In particular, we use a Student's t -copula, which belongs to the class of elliptical distributions and displays symmetric tail dependence and potentially very heavy tails. The Student's t -copula is preferred to other copula distributions because of its good fit to inflation swap data in terms of log-likelihood, Akaike information criterion, and Bayesian information criterion (see Antunes 2015). In general, for elliptical distributions, $\lambda_U = \lambda_L$, and in particular, for the Student's t -copula, the coefficients of lower and upper tail dependence are

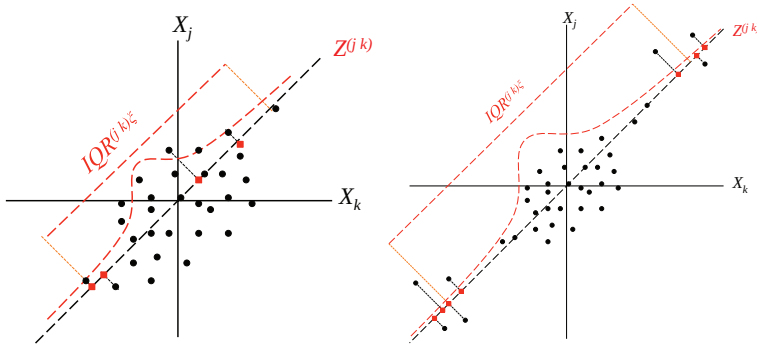
$$\lambda_U = \lambda_L = 2t_{\nu+1} \left(-\sqrt{\nu+1} \sqrt{\frac{1-\rho}{1+\rho}} \right),$$

where $t_{\nu+1}$ denotes the distribution function of a univariate Student's t -distribution with $\nu+1$ degrees of freedom and ρ is the linear correlation. The stronger the linear correlation ρ and the lower the degrees of freedom ν , the stronger is the tail dependence. However, the coefficient of tail dependence can be positive even if ρ is not.

The copula-based coefficient of conditional tail dependence is an asymptotic and parametric indicator; although its asymptotic nature could be a drawback when the estimation is performed in small samples, this measure is widely used in the literature and its quantitative interpretation is quite straightforward (it is defined as the limit of a conditional probability and hence takes values in the interval $[0,1]$).

3.1.2 TailCor Dependence Measure

As an alternative to the parametric tail dependence measure implied by copulas, we consider the TailCor index introduced by Ricci and Veredas (2013). This can be implemented under mild assumptions and presents several advantages: (i) it is non-parametric and independent of specific distributional assumptions; (ii) it performs well also in small samples, without relying on asymptotic theory; (iii) it allows to disentangle whether the evidence of tail correlations is

Figure 1. Diagrammatic Representation of TailCor

Source: Ricci and Veredas (2013, figure 1 on p. 34).

Notes: The figure shows scatter plots, along with the 45-degree line, where X_j and X_k are positively related (the pairs are depicted with circles). The left plot shows a linear relation, while the right plot shows a non-linear relation. Projecting the observations onto the 45-degree line produces the random variable $Z^{(jk)}$, depicted with squares. For illustrative purposes, the projection is shown only for the observations on the tails, but in the estimation it is done for all the observations.

caused by variables that are linearly correlated and/or non-linearly correlated; (iv) it is exact for any cutoff point of the tail; and (v) it can be computed for tails that are fatter than, equal to, or thinner than those of the Gaussian distribution.

In the following we briefly explain the intuition underlying this dependence measure using a graphical approach. The formal definition is provided in appendix 3, while technical details can be found in Ricci and Veredas (2013). The intuition underlying TailCor is that if two standardized random variables X_j and X_k are positively related (linearly and/or non-linearly), most of the time pairs of observations have the same sign. This means that looking at the scatter plot of the random variables (see figure 1), most of the pairs of observations (depicted with dots) concentrate in the northeast and southwest quadrants. When we project all the pairs on the 45-degree line, we get a new random variable $Z^{(jk)}$ (depicted with squares). The degree of dispersion of the projected dots depends on the strength of the relationship between the tails of the two random variables: if the relation is strong, the cloud is stretched around the 45-degree line

and the projected dots are very dispersed. The TailCor measure is equal—up to a normalization—to the difference between upper and lower tail quantiles of $Z^{(jk)}$.

The TailCor index can be decomposed into the sum of two components, which disentangle the degree of dependence between lower tails (DownTailCor) and between upper tails (UpTailCor) of the distributions of the two variables. Using the notation introduced above, DownTailCor is proportional to the difference between the median of the projected variable $Z^{(jk)}$ and its lower tail quantile, while UpTailCor is proportional to the difference between the upper tail quantile of $Z^{(jk)}$ and its median.

Theoretically, the TailCor index takes values between 0 and infinity; however, the actual range of variation in most financial applications is very small. The fatter the tails of the bivariate distribution, the higher the exceedance of the largest attained value over $\sqrt{2}$, which is the largest value under a bivariate Gaussian.

3.2 Data Transformation

In this section we describe the empirical strategy used to measure the co-movement between short- and long-term distributions of future inflation. In particular, we investigate the co-dependence between expectations and between the dispersion around expectations at different horizons; expectations are proxied by spot and forward inflation swap rates, while the dispersion of market beliefs is proxied by the standard deviation of option-implied distributions extracted using the LAD method (see section 2.2).¹⁰

In order to compute the co-movement measures described in the previous section, we first apply a data transformation procedure to all time series of forward inflation swaps and option-implied standard deviations. We denote by $\{Y_t\}$ the generic time series of data. The procedure involves the following steps:

¹⁰Proxying expectations with forward inflation swaps allows for tracking of short- and long-term expectations on non-overlapping horizons (e.g., one year ahead after one year versus five years ahead after five years). In our estimate we want to rely only on market data—without making any assumption on the inflation process; hence we cannot estimate forward densities and, in particular, their standard deviations.

- We take the first difference in order to get daily variations: $X_t = Y_t - Y_{t-1}$.
- We filter the time series using an AR(1)-GARCH(1,1) model of the following form in order to eliminate persistence and heteroskedasticity, which could induce spurious dependence between variables:¹¹

$$\begin{aligned} X_t &= \mu_t + \sigma_t \varepsilon_t, \quad \varepsilon_t \text{ iid } \sim N(0, 1) \\ \mu_t &= \lambda X_{t-1} \\ \sigma_t^2 &= a_0 + a(X_{t-1} - \mu_{t-1})^2 + b\sigma_{t-1}^2; \end{aligned}$$

we denote the filtered daily revisions by $\{x_t\}$.

- We map $\{x_t\}$ into numbers between 0 and 1 through their empirical marginal cumulative distribution function $\tilde{F}_x$.¹² The standardized time series is denoted by $\{u_t\}$.

The resulting filtered and standardized daily changes are used to compute our co-movement indicators.

4. Results

The data set includes daily closing quotes of zero-coupon inflation swaps and options from the first available trading day, i.e., October 5, 2009, until February 18, 2015 (source: Bloomberg). We consider swaps and options with maturity equal to one, two, three, five, seven, and ten years. Concerning options, we use strike rates ranging from 1 to 6 percent for caps and strikes from -2 to 3 percent for floors. Forward inflation swaps such as the 1y1y, the 1y2y, and the 5y5y swaps are computed from quoted spot rates.

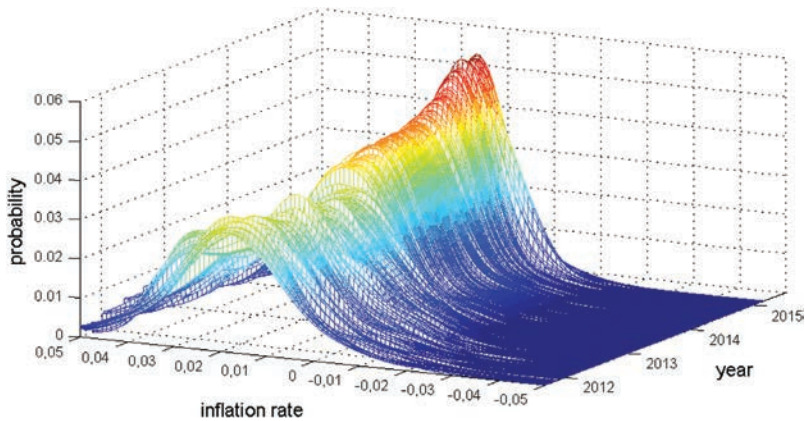
4.1 Option-Implied Distributions

For each date in the sample and each maturity horizon, we extract the unimodal LAD estimator of state prices and derive the corresponding risk-neutral distribution, thus getting a time series of

¹¹A similar approach is adopted by Christoffersen et al. (2012) to capture dynamic dependence across equity markets.

¹²This transformation, which is equivalent to a ranking, is required for copula estimation.

Figure 2. Option-Implied Risk-Neutral Distributions of Annual Euro-Area Inflation over a Ten-Year Horizon



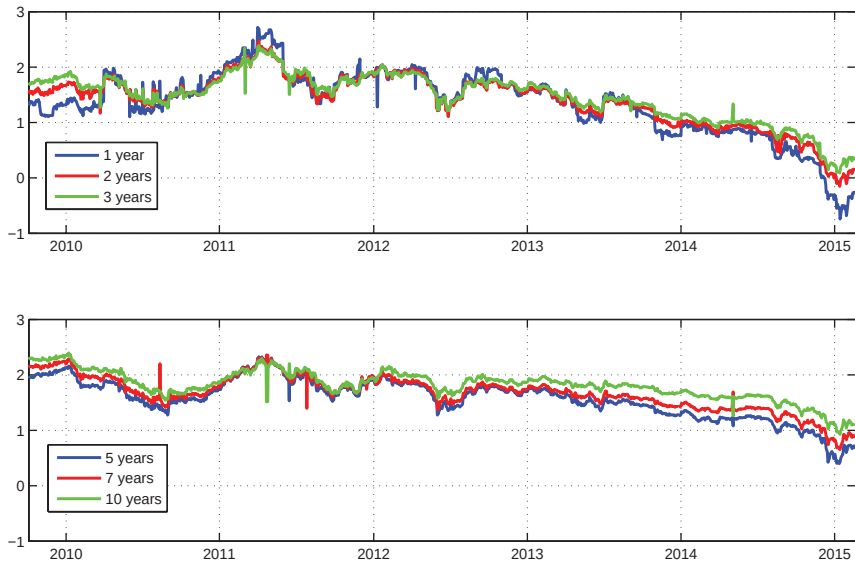
Notes: Option-implied distributions are extracted using the LAD estimator with unimodal restrictions from daily quotes between September 2011 and February 2015. The x-axis corresponds to the annual inflation rate (percentage points); the y-axis indicates the time interval (days).

implied distributions. For instance, figure 2 shows the time evolution of risk-neutral distributions of inflation on a ten-year horizon, as extracted from options data in the period September 2011–February 2015. The plot highlights the tendency of the distributions to become more and more concentrated over time, as well as a shift of the mean towards lower inflation rates.

Figure 3 shows the mean of the option-implied distributions for maturities of one, two, three, five, seven, and ten years. Inflation expectations, as proxied by the expected value of option-implied distributions, have been decreasing since 2012 for all maturities, with sharper falls for shorter horizons. The contraction of investors' beliefs halted around mid-January 2015 for all horizons.

Appendix 1 proves that for a one-year maturity the expected value of the implied distribution coincides with the fixed leg of an inflation swap having the same maturity. Comparing the time series of expected values derived from our estimates with quoted inflation rates, we obtain a very accurate match. For maturities longer than one year, the quoted inflation swap rate must be equal to a non-linear function of the implied distribution: this is confirmed

Figure 3. Means of Option-Implied Risk-Neutral Inflation Distributions (percentage points)



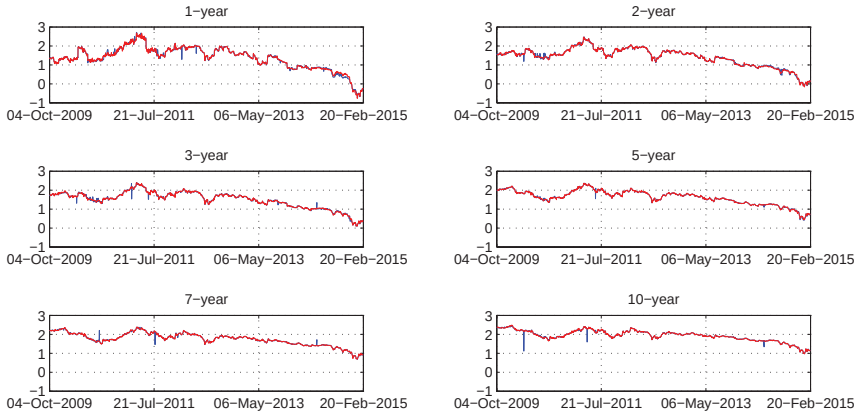
Notes: Option-implied distributions are extracted using the LAD estimator with unimodality restriction. Daily quotes of inflation caps and floors from October 2009 to February 2015 are taken from Bloomberg.

by the results of our estimates. Figure 4 shows that the difference between the quoted inflation swap rate (red line) and the one implied by our probability distributions (blue line) is negligible for all maturities.¹³ Although the estimation methodology we adopt does not force this matching through a constraint, we still recover it in quoted prices: this confirms the robustness and reliability of the approach.

Figure 5 shows the evolution of the standard deviation of option-implied distributions over time. This gives insights on the degree of uncertainty in market expectations of future inflation: the higher the standard deviation, the more dispersed are investors' beliefs and/or the more difficult it is to forecast inflation. The figure shows that uncertainty has been decreasing since 2012 for all maturities, like option-implied means. In general, the lowering of the standard

¹³Colors are shown in the online version available at <http://www.ijcb.org>.

Figure 4. Market Quotes of Inflation Swap Rates (Red Line) and Inflation Swap Rates Implied by the Probability Distributions Embedded in Option Prices (Blue Line)

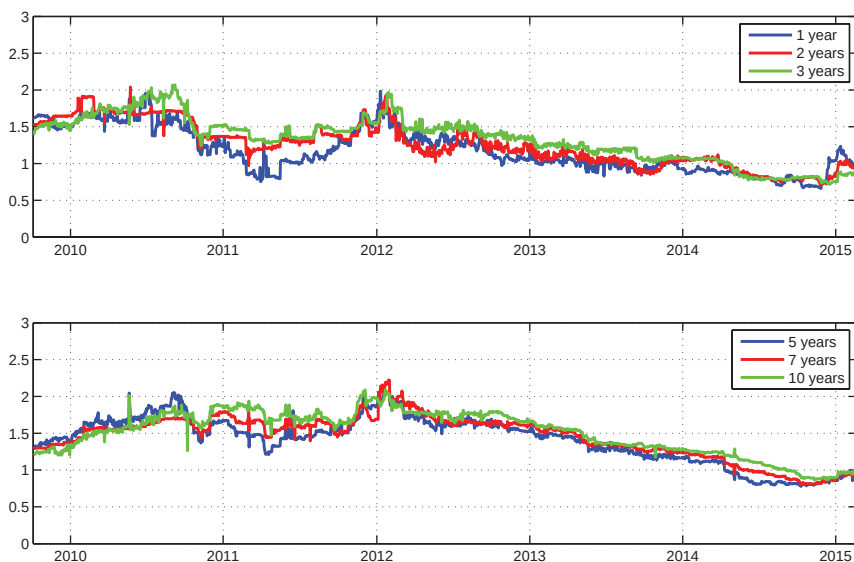


Notes: Market quotes and inflation swap rates are shown at one-, two-, three-, five-, seven-, and ten-year maturities. Option-implied distributions are extracted using the LAD estimator with unimodal restrictions. Daily quotes of inflation swaps and inflation options from October 2009 to February 2015 are taken from Bloomberg.

deviation of inflation distributions does not have a univocal interpretation: if expectations are far from the target, it indicates a higher concentration of beliefs around an undesirable outcome. In the context of long-term inflation expectations falling below the target, the attenuation of uncertainty around those expectations can then be seen as an indicator of diminished credibility of monetary policy.

Figure 6 shows that the skewness of option-implied risk-neutral inflation expectations for short horizons (one, two, and three years) became negative in the past few months after a gradual decline. For unimodal distributions such as the ones we estimated, a negative skewness indicates that the lower tail is fatter or longer than the upper tail; the most recent developments of this indicator for horizons up to three years point towards a predominance of the left tail, suggesting that market views are unbalanced towards negative inflation outcomes. Concerning maturities of five, seven, and ten years, even though the skewness has decreased from mid-2013 until January 2015, it has always remained positive.

Figure 5. Standard Deviations of Option-Implied Risk-Neutral Inflation Distributions (percentage points)

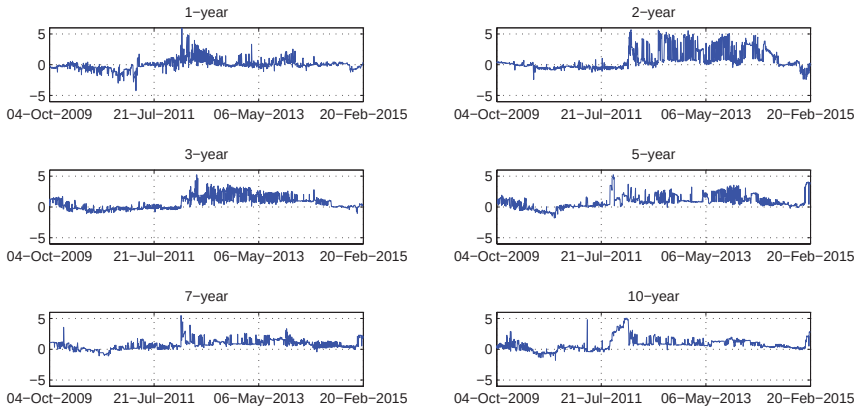


Notes: The upper panel shows maturities of one, two, and three years; the lower panel shows maturities of five, seven, and ten years. Option-implied distributions are extracted using the LAD estimator with unimodality restriction. Daily quotes of inflation caps and floors from October 2009 to February 2015 are taken from Bloomberg.

Figures 3, 5, and 6 highlight that a notable change in market-based inflation expectations has occurred, starting around mid-January 2015: expected values of inflation went up, standard deviations had a small rebound and skewness increased, especially for longer maturities. This can be interpreted as an effect of market agents anticipating the announcement of the quantitative easing program by the European Central Bank (January 22, 2015).

Figure 7 shows the risk-neutral probabilities of the average annual inflation rate over different time horizons falling below zero. Deflation probabilities at all maturities increased sharply in the last few months of 2014; for maturities up to three years, the rise started earlier—in the last quarter of 2013. Around mid-January 2015, the increase halted and deflation probabilities decreased for all time horizons. On the other hand, the probability that the average annual

Figure 6. Skewnesses of Option-Implied Risk-Neutral Inflation Distributions at Different Maturities (percentage points)



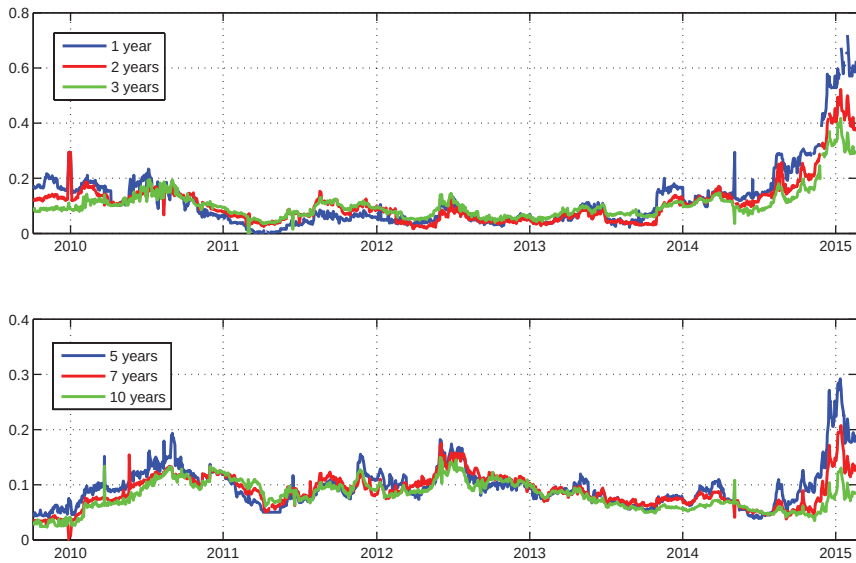
Notes: One-, two-, three-, five-, seven-, and ten-year maturities are shown. Option-implied distributions are extracted using the LAD estimator with unimodality restriction. Daily quotes of inflation caps and floors from October 2009 to February 2015 are taken from Bloomberg.

inflation rate at time different maturities falls between 1.5 and 2 percent shrank during 2014 and rebounded in early 2015 (figure 8).

Having estimated option-implied distributions, we can calculate confidence bands around the mean of expected future inflation. This allows to assess the significance of the decline in short- and long-term inflation expectations observed since 2012. Figure 9 shows the confidence bands for the expected value of option-implied probability distributions of future inflation using the 5th and 95th percentiles of the distributions, over one-, five-, seven-, and ten-year horizons. The upper limit of the confidence band fell below 2 percent for maturities up to seven years; this can be interpreted as the negative gap between expectations and the 2 percent rate being statistically significant at the 10 percent level.¹⁴

¹⁴In figure 9 we compare the level of inflation expectations with the 2 percent reference level for illustrative purposes, even though the policy objective of the European Central Bank entails the inflation rate being below, but close to, 2 percent over the medium term.

Figure 7. Risk-Neutral Probability that the Average Annual Inflation Rate at Different Maturities Is Negative

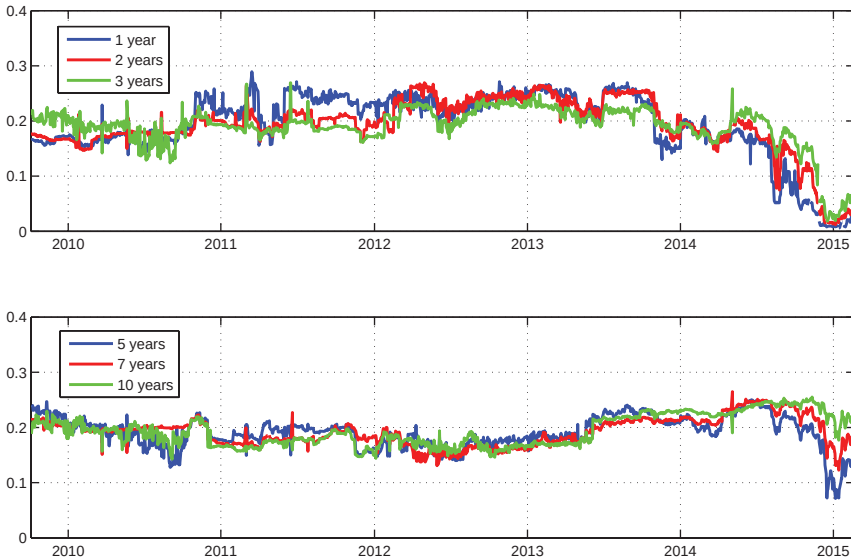


Notes: One-, two-, three-, five-, seven-, and ten-year maturities are shown. Option-implied distributions are extracted using the LAD estimator with unimodality restriction. Daily quotes of inflation caps and floors from October 2009 to February 2015 are taken from Bloomberg.

4.2 Anchoring of Long-Term Expectations

In order to construct our indicators, we select a set of measures for short- and long-term expectations from forward inflation swaps and option-implied standard deviations. Short-term expectations are proxied by the one-year spot, the 1y1y forward, and the five-year spot rates, while long-term ones are 5y5y forward inflation swaps; concerning dispersions, we compare one-year versus seven-year, one-year versus ten-year, and two-year versus ten-year standard deviations. Summary statistics for levels, daily changes, filtered values, and mapped values of each variable are reported in table 1. Variables in levels, both expectations and the dispersion of expectations, are all strongly persistent: high autocorrelations of variables in first differences are removed by the AR-GARCH filtering.

Figure 8. Risk-Neutral Probability that the Average Annual Inflation Rate at Different Maturities Falls between 1.5 and 2 Percent

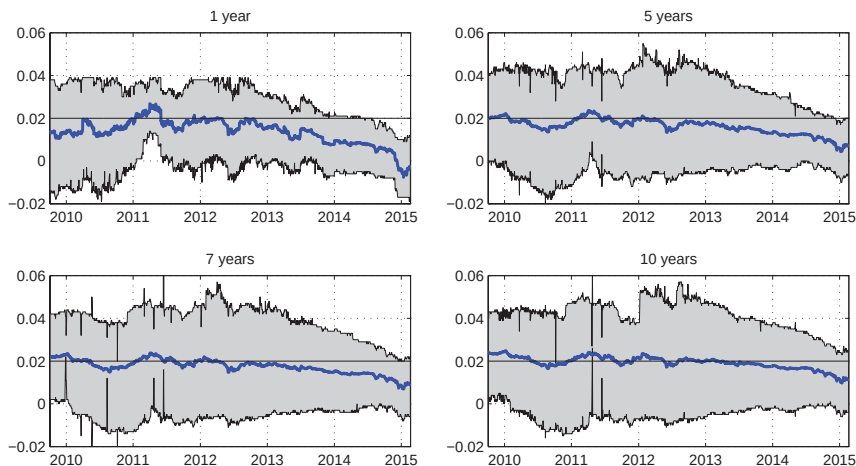


Notes: One-, two-, three-, five-, seven-, and ten-year maturities are shown. Option-implied distributions are extracted using the LAD estimator with unimodality restriction. Daily quotes of inflation caps and floors from October 2009 to February 2015 are taken from Bloomberg.

We report results based on our three measures of co-movement: the Pearson correlation coefficient (average co-movement); the coefficient of tail co-movement estimated with the Student's t static bivariate copula and the TailCor index (two measures of average co-movement in the tails); and the UpTailCor and DownTailCor indexes which track co-movements over time in upper and lower tails. Every statistic is computed using rolling windows of 250 business days of observations; nonetheless, the conclusions we draw are robust to different window lengths.

Results for mean expectations are depicted in figures 10–13. The third panel in figure 10 shows a decline in average correlations between five-year and 5y5y expectations during 2013 and the first half of 2014; a steady increase is then evident from the end of July

Figure 9. Confidence Bands for the Mean of the Option-Implied Probability Distributions of Future Inflation



Notes: Confidence bands at the 10 percent level and at one-, five-, seven-, and ten-year maturities are shown.

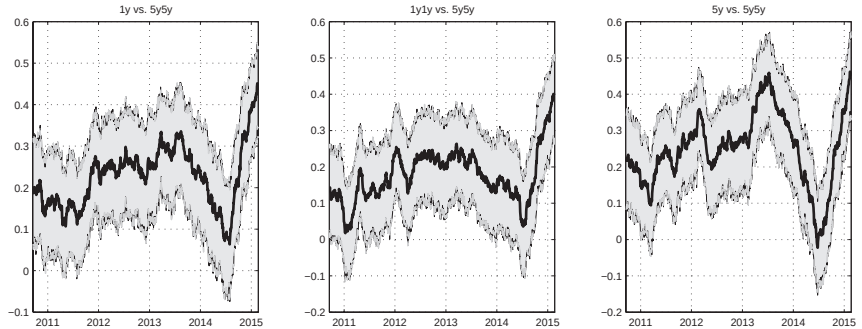
2014 up to levels close to 60 percent. A similar upward trend for linear correlations is observed in the same period using the other proxies of short-term expectations (first two panels).

These results highlight that an increase in average correlations has happened since the second half of 2014. To investigate further signs of de-anchoring, we look at the path of the copula-based coefficient of tail dependence and at the one of the TailCor index: while the first delivers mixed results (figure 11), the TailCor index suggests that the observed increase in average correlations reflects, at least in part, an increased correlation in the tails (figure 12). To detect possible asymmetries across correlations between left tails with respect to those between right tails, we look separately at each tail using the decomposition of TailCor. Figure 13 depicts the dynamics of the UpTailCor (upper-tail correlation; blue line) and DownTailCor (lower-tail correlation; red line); all panels show that the DownTailCor index increases between early 2014 and early 2015, while the UpTailCor started to rise only towards the end of 2014. This

Table 1. Summary Statistics

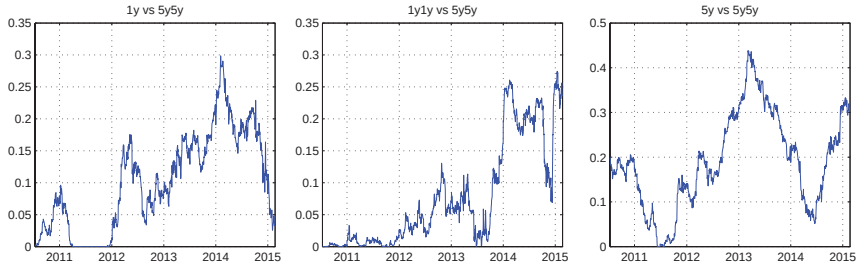
	Obs.	Mean	Std. Dev.	Autocorr.
<i>A. Mean Expectations</i>				
π_{1y}	1,404	1.36	0.60	1.00
$\Delta\pi_{1y}$	1,403	−0.00	0.06	−0.12
x_{1y}	1,403	−0.00	1.00	−0.01
u_{1y}	1,403	0.50	0.29	−0.02
π_{1y1y}	1,404	1.47	0.41	0.99
$\Delta\pi_{1y1y}$	1,403	−0.00	0.06	−0.33
x_{1y1y}	1,403	−0.00	1.00	−0.05
u_{1y}	1,403	0.50	0.29	0.00
π_{5y}	1,404	1.62	0.37	1.00
$\Delta\pi_{5y}$	1,403	0.00	0.03	0.01
x_{5y}	1,403	−0.01	1.00	0.00
u_{5y}	1,403	0.50	0.29	0.02
π_{5y5y}	1,404	2.24	0.22	0.99
$\Delta\pi_{5y5y}$	1,403	−0.00	0.03	−0.16
x_{5y5y}	1,403	−0.00	1.00	0.01
u_{5y5y}	1,403	0.50	0.29	0.05
<i>B. Option-Implied Standard Deviations</i>				
σ_{1y}	1404	1.26	1.01	0.61
$\Delta\sigma_{1y}$	1403	−0.00	0.89	−0.20
x_{1y}^{sd}	1403	0.00	1.01	−0.03
u_{1y}^{sd}	1403	0.50	0.29	0.01
σ_{2y}	1404	1.30	0.74	0.74
$\Delta\sigma_{2y}$	1403	−0.00	0.54	−0.26
x_{2y}^{sd}	1403	−0.00	1.00	−0.03
u_{2y}^{sd}	1403	0.50	0.29	−0.01
σ_{7y}	1404	1.46	0.39	0.80
$\Delta\sigma_{7y}$	1403	−0.00	0.24	−0.01
x_{7y}^{sd}	1403	0.01	1.01	0.02
u_{7y}^{sd}	1403	0.50	0.29	0.10
σ_{10y}	1404	1.51	0.30	0.98
$\Delta\sigma_{10y}$	1403	−0.00	0.06	−0.21
x_{10y}^{sd}	1403	0.04	1.00	−0.03
u_{10y}^{sd}	1403	0.50	0.29	0.06

Figure 10. Pearson Correlation Coefficient on Short-Term versus Medium- to Long-Term Market-Based Inflation Expectations



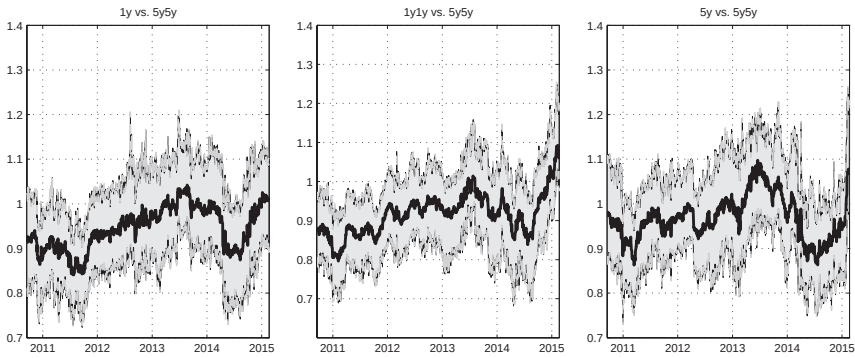
Notes: Short-term mean expectations are one year ahead, one year ahead after one year (1y1y forward inflation swap) and five years ahead, while medium- to long-term expectations are five years ahead after five years (5y5y forward). The coefficient is computed using 250 business days rolling windows. Bootstrapped confidence intervals are obtained with 1,000 replications. Sample: October 5, 2009 to February 19, 2015.

Figure 11. Index of Tail Co-movement Using the Student’s *t*-Copula on Short-Term versus Medium- to Long-Term Mean Inflation Expectations



Notes: The index ranges from 0 (no tail dependence) to 1. This index indicates the average co-movement on both upper and lower tails. Short-term mean expectations are one year ahead, one year ahead after one year (1y1y forward inflation swap) and five years ahead, while medium- to long-term expectations are five years ahead after five years (5y5y forward). Values are computed using 200 business days rolling windows. Sample: October 5, 2009 to February 19, 2015.

Figure 12. TailCor Index Computed on Short-Term versus Medium- to Long-Term Mean Inflation Expectations



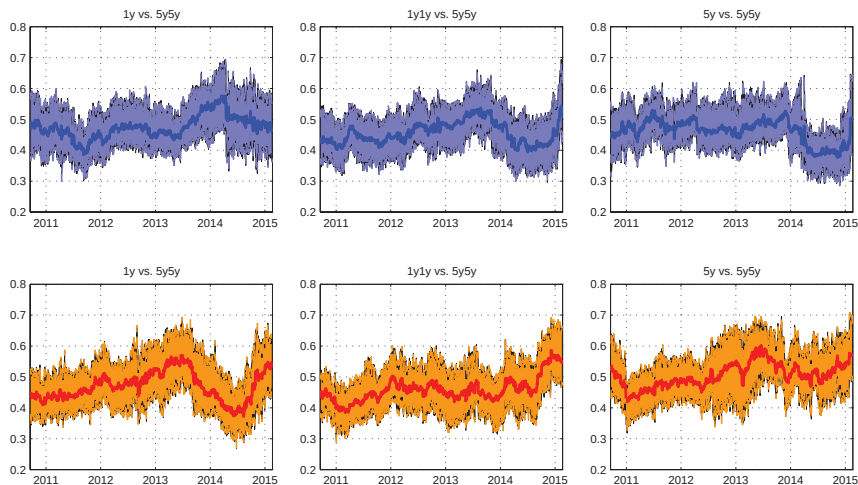
Notes: It takes values between 0 and $+\infty$; under Gaussianity and uncorrelation, the index takes the value 1. This measure indicates the average co-movement in both upper and lower tails. Short-term mean expectations are one year ahead, one year ahead after one year (1y1y forward inflation swap) and five years ahead, while medium- to long-term expectations are five years ahead after five years (5y5y forward). Values are computed using 250 business days rolling windows. Bootstrapped confidence intervals are obtained with 1,000 replications. Sample: October 5, 2009 to February 19, 2015.

evidence suggests that the correlation in the lower tail has increased earlier than the one in the upper tail: according to our interpretation, in 2014 negative events affecting short-term views have been transmitted to long-term expectations more than positive surprises. This stylized fact suggests that some de-anchoring may be occurring, and further investigation is needed.

Figures 14–17 trace the co-movement in option-implied standard deviations. Based on the rolling estimates of the Pearson coefficient, there is no clear evidence of increased correlation between short- and long-run standard deviations during the last part of the sample (figure 14). Interpreting the standard deviation as the uncertainty of market agents around their mean expectations, this points to mixed evidence on the transmission of average uncertainty towards longer maturities.

However, the analysis of tail co-movements gives interesting results. While the dynamics of the TailCor index for short- versus long-term standard deviations in the last period is not robust

Figure 13. UpTailCor (Blue Line) and DownTailCor (Red Line) Computed between Short-Term and Medium- to Long-Term Mean Expectations

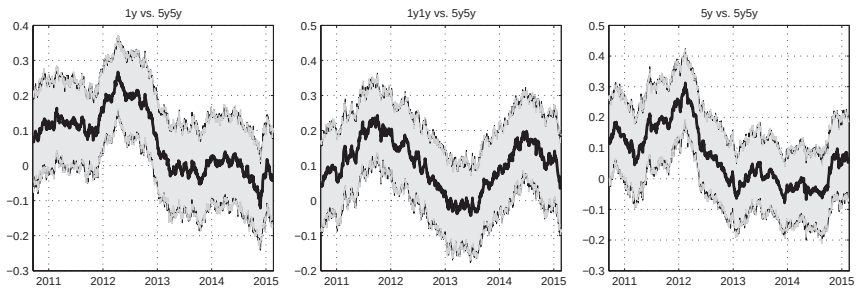


Notes: Short-term mean expectations are one year ahead, one year ahead after one year (1y1y forward inflation swap) and five years ahead, while medium- to long-term expectations are five years ahead after five years (5y5y forward). Values are computed using 250 business days rolling windows; $\xi = 0.85$, $\tau = 0.75$. Bootstrapped confidence intervals are obtained with 1,000 replications. Sample: October 5, 2009 to February 19, 2015.

to the choice of the employed proxies (see figure 16), the copula-based coefficient of tail dependence suggests a strong recent increase in tail co-movements (e.g., 1y-10y and 2y-10y couples—second and third panels of figure 15). Moreover, the inspection of UpTailCor and DownTailCor leads to opposite results with respect to the one obtained about mean expectations: the UpTailCor increases more than the DownTailCor during most of 2014. This suggests a stronger transmission from upper tail variations of short-term standard deviation to upper tail variations in long-term ones, implying that positive shocks to uncertainty have been longer lasting than shocks reducing uncertainty.

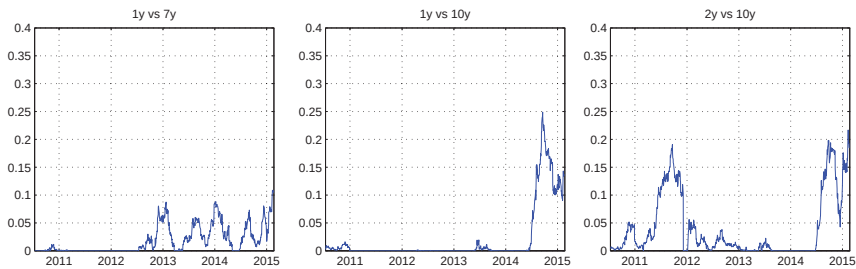
To sum up, the joint reading of the results for average expectations and option-implied standard deviations gives some useful

Figure 14. Pearson Correlation Coefficient on Standard Deviations of Short-Term versus Long-Term Option-Implied Distributions



Notes: Pairs of short-term versus medium- to long-term inflation expectations are one year ahead versus seven years ahead, one year ahead versus ten years ahead, and two years ahead versus ten years ahead. The coefficient is computed using 250 business days rolling windows. Bootstrapped confidence intervals are obtained with 1,000 replications. Sample: October 5, 2009 to February 19, 2015.

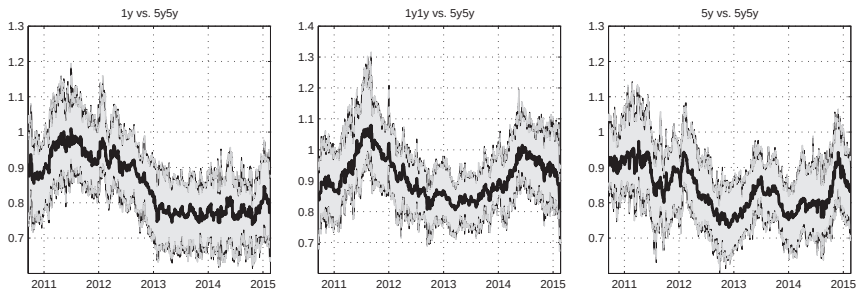
Figure 15. Index of Tail Co-movement Using the Student’s *t*-Copula on Standard Deviations of Short-Term versus Long-Term Option-Implied Distributions



Notes: The index ranges from 0 (no tail dependence) to 1. This index indicates the average co-movement on both upper and lower tails. Pairs of short-term versus medium- to long-term inflation expectations are one year ahead versus seven years ahead, one year ahead versus ten years ahead, and two years ahead versus ten years ahead. Sample: October 5, 2009 to February 19, 2015.

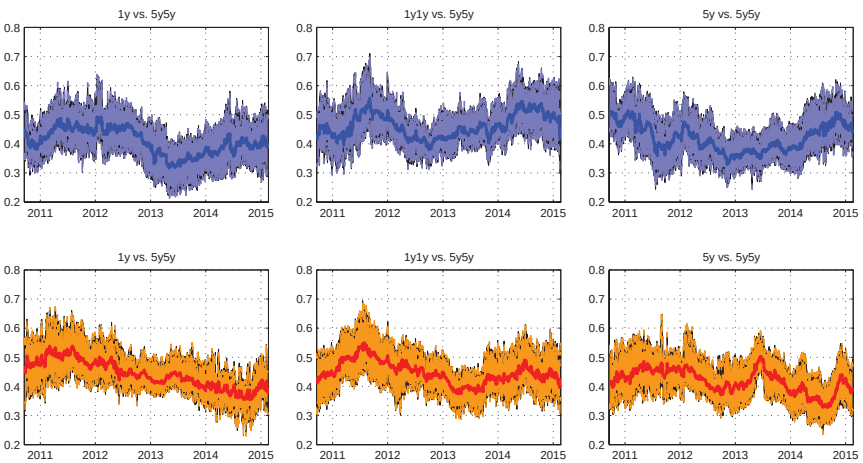
insights. During 2014, average correlations between short- and long-term inflation expectations have increased sharply; moreover, downswings in short-term expectations, possibly reflecting bad macro news or worse-than-expected data readings, have been increasingly

Figure 16. TailCor Index Computed on Short-Term versus Medium- to Long-Term Mean Inflation Expectations



Notes: This measure indicates the average co-movement on both upper and lower tails. Pairs of short-term versus medium- to long-term inflation expectations are one year ahead versus seven years ahead, one year ahead versus ten years ahead, and two years ahead versus ten years ahead. Values are computed using 250 business days rolling windows. Bootstrapped confidence intervals are obtained with 1,000 replications. Sample: October 5, 2009 to February 19, 2015.

Figure 17. UpTailCor (Blue Line) and DownTailCor (Red Line) Computed between Short-Term and Medium- to Long-Term Mean Inflation Expectations



Notes: Pairs of short-term versus medium- to long-term inflation expectations are one year ahead versus seven years ahead, one year ahead versus ten years ahead, and two years ahead versus ten years ahead. Values are computed using 250 business days rolling windows; $\xi = 0.85, \tau = 0.75$. Bootstrapped confidence intervals are obtained with 1,000 replications. Sample: October 5, 2009 to February 19, 2015.

channeled to long-term views, igniting downward revisions in average expectations and upward revisions in uncertainty. These results point to a risk of downside de-anchoring of long-term inflation expectations from the “below but close to” 2 percent target.

5. Conclusions

In this paper we propose a new method to detect possible signs of de-anchoring of inflation expectations from the medium- to long-term objective of the monetary authority. Like the commonly used pass-through approach, our technique is totally market based and does not require any identification of the surprise component incorporated in inflation readings and other macroeconomic announcements. By looking at co-movements in the tails, we assess the sensitivity of long-term expectations to extreme shocks hitting short-term ones, both positive and negative. Although a departure of long-term expectations from the monetary policy target can occur also with stable short-term views, a high degree of co-movement with short-term expectations can be seen as a sufficient condition for de-anchoring.

Applying the new estimation technique of Taboga (2016) to daily quotes of inflation caps and floors for the euro area, we are able to recover the entire probability distributions assigned by market participants to future inflation at different horizons. Focusing on mean expectations and on the dispersion of market beliefs, we look at their evolution over time, making comparisons between the long- and short-end of each term structure. In addition, we calculate confidence bands around the mean of expected future inflation in order to assess the significance of the decline in short- and long-term expectations observed since 2012. Using inflation swaps and option implied-standard deviations, we also compute linear and tail correlations between short- and long-term expectations and dispersions around them; tail co-movements are measured by copula-based coefficients of tail dependence and by the TailCor indexes.

Computing confidence bands from the estimated distributions, we find that, at the end of 2014, the upper limit of such bands fell below 2 percent for maturities up to seven years, indicating that the negative gap between expectations and the 2 percent inflation rate was statistically significant at the 10 percent level at the end of our sample period. During 2014, average correlations between

short- and long-term inflation expectations have increased sharply; moreover, downswings in short-term expectations, possibly reflecting bad macro news or worse-than-expected data readings, have been increasingly channeled to long-term views, igniting downward revisions in average expectations and upward revisions in uncertainty. Taken together, the evidence based on confidence bands and correlations leads one to conclude that some signs of downside de-anchoring of long-term inflation expectations from the 2 percent target are there and should not be overlooked.

While market-based measures of long-term inflation expectations have been unusually low in the euro area since 2013, during 2014 they also declined in the United States and in the United Kingdom.¹⁵ Even though broader international trends may in part be responsible for this common pattern, the level of anchoring of inflation expectations could be different in the three economies. Further avenues of research could include extending the estimation of option-implied distributions to U.S. and U.K. data and assessing tail co-movements within countries.

Appendix 1. LAD Method

Extraction of Option-Implied Distributions

In what follows, a quick description of the estimation method to derive option-implied probability distribution functions elaborated in Taboga (2016) is given. Let $\mathcal{I}$ be the stochastic value of the average annual inflation rate over a given time horizon. We assume that $\mathcal{I}$ has a discrete probability distribution with finite support, $R_{\mathcal{I}} = \{i_1, \dots, i_n\}$. In the absence of arbitrage, there exists an n -dimensional vector of positive state prices $\pi = (\pi_1, \dots, \pi_n)$ such that the price $\Pi(f)$ of any derivative contract on $\mathcal{I}$ having payoff $f = f(\mathcal{I})$ can be written as

$$\Pi(f) = \sum_{j=1}^n \pi_j f(i_j).$$

¹⁵Ciccarelli and Garcia (2015) investigate possible spillovers of inflation expectations across countries, finding substantial spillovers from euro-area long-term expectations onto international ones—in particular, U.S. ones—since August 2014.

In particular, the price of a zero-coupon cap with strike k and maturity $T = M$ years is given by

$$\sum_{j=1}^n \pi_j ((1 + i_j)^M - (1 + k)^M)^+,$$

whereas the price of a zero-coupon floor with strike k and maturity $T = M$ years equals

$$\sum_{j=1}^n \pi_j ((1 + k)^M - (1 + i_j)^M)^+.$$

Suppose we have the market quotes of N_C caps with strikes $\{k_1^C, \dots, k_{N_C}^C\}$ and N_P floors with strikes $\{k_1^P, \dots, k_{N_P}^P\}$. Let C be the $N_C \times 1$ vector of cap quotes and P be the $N_P \times 1$ vector of put quotes. Let F_C and F_P be $N_C \times n$ and $N_P \times n$ matrices of payoffs, defined as

$$F_{C,ij} = (s_j - K_i^C)^+ \quad \text{and} \quad F_{P,ij} = (K_i^P - s_j)^+.$$

Having set

$$Y = \begin{bmatrix} C \\ P \end{bmatrix} \quad \text{and} \quad X = \begin{bmatrix} F_C \\ F_P \end{bmatrix},$$

we can express the option prices as

$$Y = X\pi. \tag{1}$$

Since in practice market quotes encompass an error term,¹⁶ the empirical version of equation (1) is

$$Y^0 = X\pi + \varepsilon, \tag{2}$$

where Y^0 is the vector of observed market prices and ε is a vector of pricing errors. Our goal is to estimate the vector of positive state prices π given that we observe Y^0 and we know the payoff

¹⁶Pricing errors can arise for various reasons, including the bounce between bid and ask quotes, price discreteness, and state prices due to illiquidity.

X ; the risk-neutral probability distribution of $\mathcal{I}$ is then obtained by rescaling,

$$\rho = \frac{\pi}{\sum_{j=1}^n \pi_j}. \quad (3)$$

State prices are parameterized using a spline curve; Taboga (2016) shows that this is equivalent to imposing a set of linear equality restrictions. With no loss of generality, we assume that the support $R_{\mathcal{I}}$ of the distribution is equally spaced:

$$i_j = i_1 + (j - 1)\delta, \quad \delta > 0 \text{ and } j = 1, \dots, n.$$

Moreover, we assume that there exists a (piecewise cubic and twice continuously differentiable) spline function $\bar{\pi} : [s_1, s_n] \mapsto \mathbb{R}_+$ which interpolates the state prices:

$$\bar{\pi}(s_j) = \pi_j, \quad j = 1, \dots, n.$$

The number of knot points of the spline function $\bar{\pi}$ is $N_T < n - 4$; the first four elements of $R_{\mathcal{I}}$ cannot be knot points. De Boor's (1978) B-spline construction implies that the first derivative of $\bar{\pi}$ is piecewise quadratic, the second derivative is piecewise linear, the third is a stepwise constant function, and the fourth is a function that is zero everywhere except at knot points. The latter condition translates into a linear constraint on the state prices associated with knot points:

$$ND\pi = 0, \quad (4)$$

where N is a $(n - 4 - N_T) \times (n - 4)$ selection matrix whose rows are vectors of the Euclidean basis of $\mathbb{R}^{n-4}$, $D = D_{n-3}D_{n-2}D_{n-1}D_n$, and D_k is the $(k - 1) \times k$ first-difference matrix

$$D_k = \begin{bmatrix} -1 & 1 & 0 & 0 & \cdots & 0 \\ 0 & -1 & 1 & 0 & \cdots & 0 \\ \vdots & & & & & \vdots \\ \vdots & & & & & \vdots \\ 0 & 0 & \cdots & 0 & -1 & 1 \end{bmatrix}. \quad (5)$$

The LAD estimator of state prices is based on equation (2) and on the set of linear restrictions (4). An estimator minimizing absolute pricing errors is preferred to a least-squares estimator because of its computational convenience and robustness to outliers, which are known to contaminate data on option prices. The LAD estimator $\hat{\pi}_{LAD}$ of the state prices is the solution of the minimization problem

$$\begin{aligned} \hat{\pi}_{LAD} = \arg \min_{\pi} \sum_{i=1}^{N_C+N_P} w_i |Y_i^0 - X_i \pi| \\ \text{s.t. } ND\pi = 0, \pi \geq 0, \end{aligned} \quad (6)$$

where Y_i^0 and X_i are the rows of Y^0 and X , respectively, and w_i are weights assigned to pricing errors. In our estimates we set $w_i = 1/\sqrt{Y_i^0}$: this choice applies a dampening factor to deeply out-of-the-money options, which tend to have larger pricing errors in percentage terms.

The minimization problem can be written as a linear programming (LP) problem:

$$\begin{aligned} \min_z d^T z \\ \text{s.t. } Az = b, z \geq 0, \end{aligned} \quad (7)$$

where

$$d = \begin{bmatrix} w \\ w \\ 0 \end{bmatrix} \quad \text{and} \quad z = \begin{bmatrix} \varepsilon^+ \\ \varepsilon^- \\ \pi \end{bmatrix}$$

are $(2N_C + 2N_P + n) \times 1$ vectors, w is the $(N_C + N_P) \times 1$ vector of weights, ε^+ and ε^- are the positive and negative parts of the $(N_C + N_P) \times 1$ vector of pricing errors, and

$$A = \begin{bmatrix} I & -I & X \\ 0 & 0 & ND \end{bmatrix} \quad \text{and} \quad b = \begin{bmatrix} Y^0 \\ 0 \end{bmatrix}.$$

The solution of the LP problem can be found by standard and computationally inexpensive LP algorithms. The LAD estimator $\hat{\pi}_{LAD}$ is then given by the last n components of the LP solution $\hat{z}$.

Once we have computed the LAD estimator $\hat{\pi}_{LAD}$, we can get a new estimator $\hat{\pi}_U$ fulfilling a unimodality condition. Since the risk-neutral distributions are obtained by rescaling the state prices, the unimodality of π implies the unimodality of the risk-neutral distribution ρ . Let

$$\begin{aligned} \varphi(\pi) &= \arg \max_i \pi_i \quad \text{and} \quad g(\pi) = (g_1(\pi), \dots, g_{n-1}(\pi)) \\ \text{s.t. } g_i(\pi) &= \begin{cases} 1 & \text{if } i < \varphi(\pi) \\ -1 & \text{if } i \geq \varphi(\pi) \end{cases} \end{aligned}$$

The set of vectors that satisfy unimodality is $U = \{\pi \in \mathbb{R}_+^n : (D_n \pi) \circ g(\pi) \geq 0\}$, where D_n is the first-difference matrix defined in (5) and $\circ$ denotes the Hadamard or entrywise product. The unimodal LAD estimator $\hat{\pi}_U$ is then the solution of the minimization problem

$$\begin{aligned} \min_{\pi} \quad & \sum_{i=1}^{N_C + N_P} w_i |Y_i^0 - X_i \pi| \\ \text{s.t.} \quad & ND\pi = 0, \pi \geq 0 \text{ and } \pi \in U. \end{aligned} \quad (8)$$

A way to solve the problem (8) using a Bayesian version of the LAD estimator is detailed in Taboga (2016).

Inflation Swap Rates in Terms of State Prices

Let s_M be the fixed leg of a zero-coupon inflation swap with maturity M years. Let $\mathcal{I}_M$ be the (stochastic) annual rate of inflation over the next M years. Taking expectations under the risk-neutral measure Q , the following condition must hold:

$$\mathbb{E}_0^Q [D_M ((1 + s_M)^M - (1 + \mathcal{I}_M)^M)] = 0, \quad (9)$$

where D_M is the discount factor for the time interval $[0, M]$. Rewriting equation (9) in terms of state prices and taking into account that $\mathbb{E}_0^Q [D_M] = \sum_j \pi_j$, we get

$$\left(\sum_{j=1}^n \pi_j \right) (1 + s_M)^M - \sum_{j=1}^n (1 + i_j)^M \pi_j = 0.$$

Since the risk-neutral distribution d is given by $d_j = \pi_j / \sum_k \pi_k$, there follows that

$$s_M = \left(\sum_{j=1}^n d_j (1 + i_j)^M \right)^{1/M} - 1. \quad (10)$$

For $M = 1$, this equivalence boils down to

$$s_1 = \sum_{j=1}^n d_j i_j;$$

the inflation swap rate equals the mean of the option-implied distribution d . For $M > 1$, equation (10) states that the inflation swap rate is a non-linear function of the probability distribution extracted from inflation options having the same maturity.

Appendix 2. Copula Functions

DEFINITION 2 (Copula Function). *A copula is an n -dimensional distribution function $C : [0, 1]^n \rightarrow [0, 1]$ of a random vector $(U_1, \dots, U_n)$, where the marginal law of U_i is the uniform distribution on $[0, 1]$ for all $i \in \{1, \dots, n\}$.*

Copula functions are very popular in the study of multivariate distribution functions thanks to their role in imposing a dependence structure on predetermined marginal distributions. Their importance derives from Sklar's theorem, which proves that any multivariate distribution function can be characterized by a copula and that copula functions, together with univariate marginal distribution functions, can be used to construct multivariate distribution functions.

THEOREM 1 (Sklar's Theorem). *Let H be an n -dimensional distribution function with marginals $F_1, \dots, F_n$. Then an n -copula C exists such that, for each $x \in R^n$,*

$$H(x_1, \dots, x_n) = C(F_1(x_1), \dots, F_n(x_n)).$$

If the marginals $F_1, \dots, F_n$ are all continuous, then C is unique; otherwise C is univocally determined on $(\text{Ran} F_1 \times \text{Ran} F_2 \times \text{Ran} F_n)$

(where $\text{Ran}F_i$ denotes the rank of F_i). Conversely, if C is an n -copula and $F_1, \dots, F_n$ are distribution functions, then the function H defined above is an n -dimensional distribution function with marginals $F_1, \dots, F_n$.

The proof of this theorem can be found, e.g., in Nelsen (2006).

The main feature of Sklar's theorem is that for continuous multivariate distribution functions, the univariate marginals and the multivariate dependence structure can be separated and the dependence structure can be represented by a copula.

Let F be a univariate distribution function. Let us recall that the generalized inverse of F is defined as $F^{-1}(t) = \inf\{x \in \mathbf{R} | F(x) \geq t\}$ for each t in $[0, 1]$, with the usual convention that $\inf(\emptyset) = -\infty$.

An important corollary of Sklar's theorem, which is fundamental in the study of copulas and their applications, is the following:

COROLLARY 1. *Let H be an n -dimensional distribution function with continuous marginals $F_1, \dots, F_n$ and copula C . Then for each $u \in [0, 1]^n$,*

$$C(u_1, \dots, u_n) = H(F_1^{-1}(u_1), \dots, F_n^{-1}(u_n)).$$

In the following we recall the Student's t -copula that we use in the paper.

DEFINITION 3 (Student's t -Copula). *The Student's t -copula can be written as*

$$C_{\rho, \nu}(u, v) = \int_{-\infty}^{t_{\nu}^{-1}(u)} \int_{-\infty}^{t_{\nu}^{-1}(v)} \frac{1}{2\pi(1-\rho^2)^{1/2}} \times \left\{ 1 + \frac{x^2 - 2\rho xy + y^2}{\nu(1-\rho^2)} \right\}^{-(\nu+2)/2} ds dt,$$

where ρ and ν are the parameters of the copula, and t_{ν}^{-1} is the inverse of the standard univariate Student's t -distribution with ν degrees of freedom, expectation 0, and variance $\frac{\nu}{\nu-2}$.

Student's t -copula allows for joint fat tails. Increasing the value of ν decreases the tendency to exhibit extreme co-movements. The

Student's t -dependence structure supports joint extreme movements regardless of the marginal behavior of the individual variables.

Appendix 3. TailCor Measures

Let X_{jt} be the j -th element of the random vector $\mathbf{X}_t$. Denote by Q_j^τ its τ -th quantile for $0 < \tau < 1$, and let $IQR_j^\tau = Q_j^\tau - Q_j^{1-\tau}$ be the τ -th interquantile range. Let Y_{jt} be the standardized version of X_{jt} :

$$Y_{jt} = \frac{X_{jt} - Q_j^{0.50}}{IQR_j^\tau}.$$

By standard trigonometric arguments, the projection of (Y_{jt}, Y_{kt}) onto the 45-degree line is

$$Z_t^{(jk)} = \frac{1}{\sqrt{2}}(Y_{jt} + Y_{kt}),$$

and the tail interquantile range is

$$IQR^{(jk)\xi} = Q^{(jk)\xi} - Q^{(jk)1-\xi},$$

where $Q^{(jk)\xi}$ is the ξ -th quantile of $Z_t^{(jk)}$. The larger ξ is, the further we explore the tails.

TailCor is then defined as follows (Ricci and Veredas 2013):

DEFINITION 4 (TailCor). *Under technical assumptions, TailCor between X_{jt} and X_{kt} is*

$$TailCor^{(jk)\xi} := s_g(\xi, \tau) IQR^{(jk)\xi},$$

where $s_g(\xi, \tau)$ is a normalization such that under Gaussianity and linear uncorrelation $TailCor^{(jk)\xi} = 1$, the reference value.

A table with values of $s_g(\xi, \tau)$ for a grid of reasonable variables for τ and ξ can be found in Ricci and Veredas (2013), appendix T.

When interest lies in the tail of one side of the distribution, downside TailCor and upside TailCor can be used:

DEFINITION 5 (Downside TailCor). *Downside TailCor is defined as*

$$TailCor^{(jk)\xi-} := s_g(\xi, \tau) IQR^{(jk)\xi-},$$

where $IQR^{(jk)\xi-} = Q^{(jk)0.50} - Q^{(jk)1-\xi}$.

DEFINITION 6 (Upside TailCor). *Upside TailCor is defined as*

$$TailCor^{(jk)\xi+} := s_g(\xi, \tau) IQR^{(jk)\xi+},$$

where $IQR^{(jk)\xi+} = Q^{(jk)\xi} - Q^{(jk)0.50}$.

The estimation procedure consists of four simple steps that can be followed under technical assumptions:

- (i) Standardize X_{jt} and X_{kt} .
- (ii) Estimate the IQR of the projection: $\hat{IQR}_{\hat{Z}, T}^{(jk)\xi}$.
- (iii) Find the normalization $s_g(\xi, \tau)$ from the table.
- (iv) Compute $TailCor_{\hat{Z}, T}^{(jk)\xi} = s_g(\xi, \tau) \hat{IQR}_{\hat{Z}, T}^{(jk)\xi}$.

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Monetary Policy, Financial Conditions, and Financial Stability*

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We review a growing literature that incorporates endogenous risk premiums and risk-taking in the conduct of monetary policy. Accommodative policy can create an intertemporal tradeoff between improving current financial conditions at a cost of increasing future financial vulnerabilities. In the United States, structural and cyclical macroprudential tools to reduce vulnerabilities at banks are being implemented, but may not be sufficient because activities can migrate and there are limited tools for non-bank intermediaries or for borrowers. While monetary policy itself can influence vulnerabilities, its efficacy as a tool will depend on the costs of tighter policy on activity and inflation. We highlight how adding a risk-taking channel to traditional transmission channels could significantly alter a cost-benefit calculation for using monetary policy, and that considering risks to financial stability—as downside risks to employment—is consistent with the dual mandate.

JEL Codes: E44, E52, E58, G21, G28.

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1. Introduction

Monetary policy works by affecting financial conditions. This paper addresses how monetary policy also affects financial stability, and the roles for macroprudential and monetary policies for reducing risks to financial stability. A growing body of research indicates that accommodative monetary policy given financial frictions can increase risks to financial stability by leading to buildups of financial vulnerabilities, which can increase future downside risks to the real economy.¹ In particular, recent research is advancing on how accommodative monetary policy and compressed risk premiums on assets affect financial vulnerabilities, such as excess credit of households and businesses, and high leverage or maturity transformation at financial intermediaries. In addition, because accommodative policy can create an intertemporal tradeoff between improving current financial conditions and increasing future financial vulnerabilities, consideration should be given to risks to financial stability in the setting of monetary policy. How it should be considered will depend on its relative effectiveness and interactions with macroprudential policies.

In this paper, we provide a broad review of transmission channels of monetary policy through financial conditions and financial vulnerabilities, and document a significant role for monetary policy in the buildup of financial vulnerabilities. Financial frictions such as asymmetric information have been foundational for macro models that include credit cycles and the effects of asset prices on collateral values and borrowing constraints. Other financial frictions that could result in vulnerabilities include agency costs, institutional investor sticky nominal return targets, and financial firms' risk models and limited liability. Moreover, individual borrowers and lenders might not have incentives to take into account their effects on aggregate debt when they make their own private decisions. These financial frictions can lead to an intertemporal tradeoff between financial

¹Financial conditions refer to broad funding conditions, including risk premia for risky assets above the risk-free term structure. When financial frictions are present, policy may need to be set tighter or easier than neutral to achieve an optimal policy outcome. Accommodative policy refers to a stance of monetary policy that is more expansionary than would be the case in the absence of financial frictions.

conditions and financial stability for setting monetary policy, where loose financial conditions based on time-varying risk premia in asset prices and risk-taking by borrowers and lenders could lead to higher future vulnerabilities that make the system more prone to amplify negative shocks.

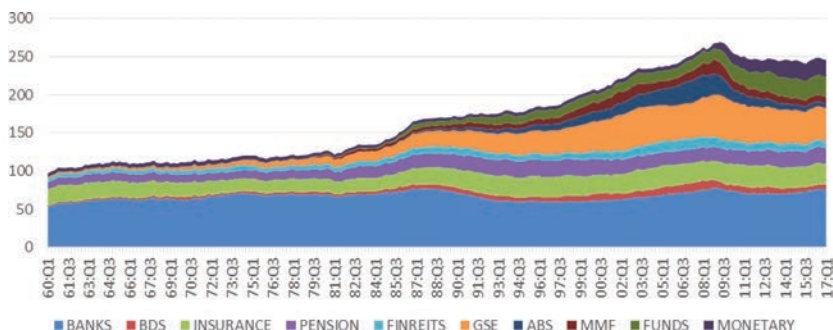
Macroprudential policies—both structural through the cycle and cyclical time varying—are usually viewed as the primary tools to mitigate vulnerabilities and promote financial stability. These regulatory and supervisory tools, such as bank capital requirements or sector-specific loan-to-value ratios, may be used to lean against the wind by tightening financial conditions in a targeted way, and to shore up the resilience of the financial system to possible adverse shocks, such as the bursting of an asset bubble.

Monetary policy works similarly to lean against the wind, though it is not targeted. It may be less efficient than macroprudential policy if the financial vulnerability is narrow. In addition, it does not directly increase resilience in the same way that higher capital at banks can. These considerations support the current prevailing approach of a clear separation in responsibilities: Monetary policy should focus on the inflation–real activity tradeoff, and, conditional on the stance of monetary policy, macroprudential policy should be used to mitigate vulnerabilities to achieve an acceptable level of systemic risk.

Proponents of an alternative non-separable approach point to the effects that monetary policy has on financial vulnerabilities in addition to financial conditions. They also would point out that macroprudential policies may have limited reach to regulated financial firms, and restricting their activities may simply push the activities into a non-prudentially regulated sector. In the United States, this sector is extensive: non-financial credit market debt held by non-bank financial firms greatly exceeds debt held by banks (figure 1 and Adrian, Covitz, and Liang 2015). Debt held by non-banks, which includes securitizations and entities funded by short-term liabilities, hit a peak in 2008 at over 100 percent of GDP, larger than the debt held by banks.

In contrast to macroprudential policies, monetary policy will affect costs for all borrowers and lenders—it “gets in all the cracks” (Stein 2014). Moreover, monetary policy is less subject to the criticism that regulators are making non-market credit-allocation

**Figure 1. Credit Market Debt Outstanding
(percent of GDP)**



Source: Financial Accounts of the United States.

Note: Shaded areas appear in color in the online version, available at <http://www.ijcb.org>.

decisions. Relatedly, monetary and macroprudential policies should not be separated given their similar transmission channels to the real economy through asset prices, credit, and financial intermediation, and the policy stance of one affects the effectiveness of the other.

The clean separation view is supported by cost-benefit analysis of a “lean-against-the-wind” policy in Svensson (2016). In that framework, the costs of monetary policy to lean against the wind are a higher unemployment rate in the current period, and the benefits are reduced borrowing by households, which leads to a lower probability of a financial crisis in the future, an explicit recognition of an intertemporal tradeoff. He concludes the costs greatly exceed the benefits, based on parameters from the Swedish economy on credit growth to monetary policy and estimates of the probability of a crisis based on Schularick and Taylor (2012). Ajello et al. (2016) allow for monetary policy to reduce the probability of a crisis in a DSGE model, and they find some role for adjusting monetary policy based on the U.S. economy, but by very little given that the probability and the elasticity with respect to monetary policy is small. Gourio, Kashyap, and Sim (2016) examine the welfare implications for using monetary policy to lean against the wind, and derive positive net benefits when the costs of financial crises lead to plausibly large permanent losses in output.

Our paper is a contribution to this debate. We provide a review of current research on the effects of monetary policy on financial vulnerabilities through an endogenous increase in risk-taking, channels not typically considered in traditional macro models. This review creates a strong case against the conclusion that the costs of a lean-against-the-wind policy would always greatly exceed the benefits. We then review the research on roles for macroprudential and monetary policy to mitigate vulnerabilities, including the limitations of macroprudential policies in market-based financial systems. Finally, we present analysis of the costs and benefits of using monetary policy to lean against the wind, by using Svensson's (2016) cost-benefit framework. We use this framework because it offers a very transparent way to highlight some key assumptions that are critical to estimating the costs and benefits—specifically, about the severity of a crisis, the likelihood of a crisis, and its sensitivity to monetary policy if monetary policy is used preemptively. While we show that the net cost calculation is sensitive to assumptions, the primary objective of the analysis is to highlight that more research is needed to better quantify the magnitude of monetary policy on financial vulnerabilities through asset prices and endogenous risk-taking.

The remainder of the paper is organized as follows. Section 2 provides a conceptual framework for the relationship between monetary policy, financial conditions, and financial vulnerabilities, also considering macroprudential policy. Section 3 reviews recent literature on the transmission channels of monetary policy, particularly focusing on the potential buildup of financial vulnerabilities, using the financial stability monitoring framework described by Adrian, Covitz, and Liang (2015), as summarized in table 1. It focuses on specific financial vulnerabilities—pricing of risk, leverage, maturity and liquidity transformation, and interconnectedness and complexity—across four sectors—(i) asset markets, (ii) the banking sector, (iii) shadow banking, and (iv) the non-financial sector. Section 4 discusses how macroprudential policy tools can address financial vulnerabilities. Section 5 reviews papers that consider the interactions of macroprudential and monetary policies. Section 6 provides the cost-benefit analysis. Section 7 concludes.

Table 1. Monitoring Vulnerabilities in Different Sectors (Adrian, Covitz, and Liang 2015)

Sectors	Price of Risk	Leverage	Maturity/Liquidity Transformation	Interconnections and Complexity
Non-financial Sector	Underwriting standards (LTVs, DTIs)	Credit-to-GDP Leverage and debt service burdens of households, business, and government Investor leverage	Use of short-term or floating-rate debt	
Asset Markets	Risk premiums and non-price terms in equities, credit, real estate Term premiums for rates		Dealer-based finance Carry trades Mutual funds ETFs	Derivatives and counterparties
Banking Sector	Risk-taking in credit and rates Underwriting standards	Regulatory capital ratios, banks and broker-dealers Market measures of risk and capital Post-stress capital from stress tests Securitization tranches Regulatory capital arbitrage Hedge funds Use of derivatives to mimic leverage	Financial firm liabilities, maturities Secured and unsecured funding	Intrafinancial assets and liabilities Common asset holdings, correlated risks Size, critical functions,
Shadow Banks, Financial Markets	Securities issuance Underwriting standards		Agency REITs ABCP conduits Repo markets Securities lending MMFs STIFs	CCPs New financial products

2. Conceptual Framework for Monetary Policy and Financial Stability

This section describes in more detail the framework for an intertemporal tradeoff between financial conditions and financial vulnerabilities for monetary policy. This tradeoff is typically not considered in the literature on monetary policy. In traditional monetary policy settings, the inflation–real activity tradeoff determines the stance of financial conditions. For example, in typical New Keynesian models, the Taylor rule—which describes the stance of monetary policy with respect to inflation and real activity—is derived by taking first-order approximations around the steady state, thus explicitly abstracting from downside risk considerations.

As discussed in detail in this paper, when financial intermediation is added to these models, interest rate changes can also affect loan supply through credit market frictions, such as asymmetric information between borrowers and lenders that gives rise to an external finance premium. The size of the external finance premium depends on the balance sheet conditions of the borrower: When monetary policy is loose and asset values are high, higher net worth of borrowers eases borrowing constraints and allows for excess credit accumulation. In addition, accommodative monetary policy may lead to an increase in risk-taking by financial institutions and investors: Low interest rates could incent investors who have nominal return targets to reach for yield. Low rates could pressure profit margins of banks and incent them to hold riskier assets, or higher asset values could lead them to underestimate risk, given their risk-management models and limited-liability corporate structures. Low rates that boost asset values also may incent carry trades based on short-term funding, often secured by the assets, and allow for excessive maturity transformation. These channels for monetary policy lead to an increase in vulnerabilities, leaving the financial system less resilient to adverse shocks and hence raising future risks to financial stability.

Cost-benefit analysis is a useful framework to contrast the traditional models with those that consider financial intermediation. In traditional models without financial frictions, increases in credit would reflect improved economic fundamentals, and the costs of using monetary policy to reduce credit and the probability of a crisis would far exceed the benefits. But in models with financial

intermediation and frictions that lead to financial vulnerabilities, there may be net benefits to using monetary policy since less credit and lower asset valuations could reduce the probability and severity of a future recession.

This framing highlights a few issues that are important for this paper. First, financial conditions and financial stability are not the same. Declining asset prices and higher volatility due to downward revisions to expected cash flows are a deterioration in financial conditions, not signs of financial instability. A financial system that is performing its function to allocate capital to its best uses, without the fragilities of borrowers or lenders to amplify revisions to the outlook, is a stable financial system. That is, financial stability reflects a resilient financial system that is less likely to amplify adverse shocks; financial instability arises when negative shocks are amplified by vulnerabilities, leading to non-linear outcomes and tail events.

In addition, monetary policy works through financial conditions on expected economic outcomes, but risks to financial stability involve potential tail risks. The tail risks to future macroeconomic outcomes manifest only in some states of the world, when adverse shocks are realized. These dimensions are important because they greatly complicate efforts to incorporate financial stability in the determination of monetary policy. Policymakers would need to look beyond expected conditions for downside risks that arise with uncertain probability in the future. Thus such outcomes can be discounted readily, but when they occur, the consequences can be severe. Future downside risks are difficult to include in an objective function.

The distinction between vulnerabilities and risks is a fundamental one. Vulnerabilities are the amplification mechanisms that amplify adverse shocks. Risks are the realizations of adverse shocks. While the dimensionality of risks is very high—and risks are thus difficult to monitor and assess—the assessment of vulnerabilities is more manageable. The paper thus focuses on the tradeoff between financial conditions and financial vulnerabilities.

3. Monetary Policy Transmission and Financial Stability

This section reviews empirical and theoretical studies about the linkages between monetary policy, financial conditions, and financial

stability by sector. As highlighted by table 1, we could summarize the monetary policy transmission channels either by four sectors of the financial system or by vulnerabilities. We chose the former because existing studies are much more focused on sectors. In either case, however, it is the combination of vulnerabilities across sectors that increases the potential for systemic risks, rather than any individual category on its own. The monetary policy transmission channels in the four sectors for financial conditions and vulnerabilities because of financial frictions can be summarized as follows (see table 2):

- Non-financial Sector: Easier monetary policy eases borrowing constraints and boosts credit growth, but endogenous risk-taking of lenders can reduce underwriting quality and increase debt burdens of borrowers who do not consider externalities of deleveraging.
- Asset Markets: Easier monetary policy improves financial conditions by lowering the risk-free term structure and increasing risky asset prices, but agency problems and investors' reach for yield behavior can lead to compressed risk premiums and a greater risk of a price reversal.
- Banking Sector: Easier monetary policy increases lending, but endogenous risk-taking and risk-shifting can lead to higher leverage of banks and broker-dealers, and greater loan supply.
- Shadow Banking: Easier monetary policy increases financial intermediation outside the banking sector as asset prices increase, but endogenous risk-taking can lead to higher leverage and maturity transformation not backed by deposit insurance.

3.1 Non-financial Sector

3.1.1 Financial Conditions

Easier monetary policy leads to an expansion of credit by encouraging borrowing at lower interest rates. In macroeconomic models without financial-sector frictions, credit growth represents an increase in demand to finance household and business spending. The balance sheet channel is a standard transmission channel for monetary policy, which emphasizes the impact of policy on the

Table 2. Monetary Policy Transmission on Financial Conditions and Financial Stability in Different Sectors

Sectors	Financial Conditions	Financial Stability
Non-financial Sector	Borrowing conditions Balance sheet channel Credit growth or credit/GDP	Deterioration in underwriting standards Excess leverage • Fire-sale externalities • Negative demand externalities
Asset Markets	Risk-free term structure Higher asset prices Lower risk premiums	Compressed risk premiums • Reach for yield because of nominal targets • Supported by leverage from an external finance premium, asymmetric information • Asset managers that prefer yield income or are evaluated based on relative performance Low volatility and low risk premiums • Procyclical risk-management practices • Mismeasurement of risk
Banking Sector	Credit channel	Procyclical leverage of banks and dealers • Procyclical risk-management practices and inflated collateral values Risk-shifting channel reduces the quality of credit • Low bank capital
Shadow Banks, Financial Markets	Securitization Liquidity creation Maturity transformation by non-bank intermediaries	Procyclical dealer-intermediated leverage • Procyclical risk-management practices and inflated collateral values Excessive maturity transformation • Short-term funding fragilities Regulatory arbitrage

net worth of borrowers when lenders face asymmetric information (the seminal contribution by Bernanke and Gertler 1989 was further extended by Kiyotaki and Moore 1997, and Bernanke, Gertler, and Gilchrist 1999). Empirical evidence on the balance sheet channel, often referred to as the “financial accelerator,” is extensive. For example, Levin, Natalucci, and Zakrajšek (2004) find a sharp rise in external finance premiums for businesses during the 2001 recession, and Iacoviello (2005) shows that changes in home equity affect household borrowing and spending by more than a conventional wealth effect. Violations of loan covenants, which often are tied to the net worth of the borrower, may be a mechanism through which monetary policy leads to cutbacks by firms in investment and employment (Chava and Roberts 2008; Falato and Liang 2016).

3.1.2 Financial Stability

The literature generally finds that large shocks are needed for the financial accelerator to matter. Furthermore, in the financial crisis of 2007–09, borrower balance sheet frictions alone were not sufficient to explain the large observed amplification effects on the economy. As a result, the literature has been evolving to add additional frictions to explain non-financial sector credit and its interactions with other imbalances, including high asset valuations and fragile financial intermediaries.

Rapid private credit growth has been found to be a robust predictor of banking crises, and the cumulative growth as reflected in the credit-to-GDP gap for the private non-financial sector is viewed as a high-quality (high signal-to-noise) indicator for the likelihood of financial instability (see Borio and Lowe 2002, Borio, Drehmann, and Tsatsaronis 2011). Borio and Lowe (2002) suggest it is the interaction of credit and asset prices that is most costly to the economy when a credit boom unwinds, and that this combination may be a byproduct of strong demand pressures from accommodative monetary policy in a low-inflation environment when monetary policy is focused solely on price stability.

Excess credit may also arise because borrowers do not consider the externalities when making their individual borrowing decisions. Lorenzoni (2008) generates excessive borrowing *ex ante* and excess volatility in investment *ex post*, due in part to limited ability to

commit to future payments. Borrowers have limited access to outside funds, so they are forced to fire-sell assets when they are hit by bad shocks. Inefficiencies arise because borrowers do not consider the general equilibrium of fire sales on asset prices. Korinek and Simsek (2016), in a model of deleveraging, show that borrowers do not take into account the negative externalities of leverage on aggregate demand when they make their own borrowing decisions, which leads to excessive credit. In their model, tighter monetary policy could be used to address aggregate demand externalities caused by leverage.

Target rates of return that lead to “reach for yield” or risk-management practices based on past volatility could also lead to excess private credit. Accommodative monetary policy in these situations could lead to lower risk premiums and increased risk-taking at lenders (as discussed below) and more credit at riskier borrowers. For example, Becker and Ivashina (2015) document that insurance companies’ reach for yield behavior is more pronounced during economic expansions, which they can test because credit ratings used to determine requirements are imperfect measures of risk. They also find greater bond issuance by riskier non-financial corporations with more pronounced reach for yield by insurance firms, suggesting *ex post* greater systematic risk and volatility.

Whether the monetary policy transmission channel to excess credit is direct or indirect through financial intermediaries, the consequences of a forced unwind of excess private-sector credit are substantial. Jordà, Schularick, and Taylor (2013), in a cross-section study, show that excess credit growth in the period preceding a business-cycle peak tends to be associated with more severe recessions, in both normal recessions and those associated with financial crises. In a study of private non-financial credit in the United States, Aikman et al. (2016) find in a threshold VAR analysis that the implications of greater financial conditions (investor risk appetite) and the credit-to-GDP gap depend on whether the credit gap is above or below its trend. When it is below trend, looser financial conditions lead to a sustained economic expansion and a modest increase in the credit gap. However, when the gap is above trend, looser financial conditions lead initially to an expansion, but over time lead to a sharp increase in an already-high credit gap, which sets the stage for an unwind and a recession.

In the household sector, Mian and Sufi (2009) show that a rise in household leverage measured at the county level, likely due to an increase in the supply of credit, is a strong predictor of recession severity. Mian and Sufi (2011) show that borrowing against home equity was responsible for a significant share of the rise in leverage, and subsequent new defaults. Moreover, Mian and Sufi (2012) suggest that lower demand driven by the deterioration in household balance sheets is responsible for a large share of job losses during 2007–09. For businesses, those that are more leveraged are forced to make larger cuts in investment and employment upon default or loan covenant violations (Opler and Titman 1994; Chava and Roberts 2008; Falato and Liang 2016).

Credit stresses at households and businesses also can lead to mounting losses at financial institutions. Such losses that impair capital adequacy of regulated banks and shadow banks can restrict credit availability and further reduce aggregate demand through an adverse feedback loop in which less aggregate demand reduces the value of collateral and makes it more difficult for the non-financial sector to service their debt, further increasing losses to the financial sector (Brunnermeier and Sannikov 2014a).

3.2 Asset Markets

3.2.1 Financial Conditions

The most direct transmission channel of monetary policy is via the expected path of future short rates. Monetary policy also affects the pricing of risky assets, such as in equity, credit, housing, and other risky asset markets, through expected cash flows and risk premia. Bernanke and Kuttner (2005) document that positive monetary policy surprises generate negative stock returns, not mostly through the effects on real rates but through its effects on expected returns or expected future dividends. In addition, others have shown that easing of monetary policy tends to reduce credit risk premiums on corporate bonds (Gertler and Karadi 2013; Greenwood and Hanson 2013; Gilchrist, López-Salido, and Zakrajšek 2015). Bekaert, Hoerova, and Lo Duca (2013) find, based on the dynamics of the VIX, that tightening shocks lead to increases in investor risk aversion.

Moreover, a number of studies document that the majority of movements in asset prices reflects movements in the equilibrium compensation for risk. For example, the time variation in Treasury returns primarily is due to changes in the pricing of risk rather than to changes in expectations of future short rates (see Campbell and Shiller 1984, Cochrane and Piazzesi 2005, and Cochrane 2011). Similarly, the majority of variation in credit spreads is due to investors' compensation for the risk of potential credit losses in the future rather than expected losses (see, e.g., Elton et al. 2001 and Huang and Huang 2012). For equity prices and house prices, valuation measures such as the dividend payout or the price-to-rent ratio tend to exhibit swings that are larger than can be explained by fundamentals (see Campbell and Shiller 1988 for equity returns, and Case and Shiller 2003 and Campbell et al. 2009 for house prices).

But the link from monetary policy to asset prices does not necessarily suggest that loose policy increases risks to financial stability. For that to happen, compression in risk premiums must be accompanied by a buildup of other financial imbalances. We turn to a discussion of these issues next.

3.2.2 Financial Stability

High valuation levels in asset markets are a financial vulnerability if combined with leverage and maturity transformation of financial-sector lenders or high credit of non-financial borrowers that could lead to an asymmetric unwinding of risk premiums.² Of course, it is difficult to assess in real time when valuation levels are excessive; this can only be judged by historical standards using asset pricing models. For example, in the run-up of equity market valuations in the late 1990s, many argued that the very high price-earnings ratios were justified by a structural break in productivity. Similarly, in the run-up of house prices in the early to mid-2000s, many argued that high price-to-rent ratios were sustainable because of improved credit intermediation technologies and less volatile household income. In our monitoring approach, high valuations that are supported by

²Early literature on monetary policy and asset price bubbles considered such bubbles without consideration of financial frictions (e.g., Bernanke and Gertler 1999). We discuss that literature in detail in section 5.

structural breaks, because “this time is different,” would represent a vulnerability that warrants additional attention. In particular, rather than focusing on whether or not valuation levels can be justified, the focus should be on potential systemic consequences if prices were to fall. Asset pricing models for interest rates, credit products, real estate, and equities are needed to assess valuations and are an important first step in assessing overall system vulnerabilities.

Accommodative monetary policy combined with financial frictions may lead to high valuations and compressed risk premiums for financial assets for a number of reasons. Rajan (2005, 2006) argues that low interest rates can lead to compressed risk premiums because they increase the incentives for investors to “reach for yield.” This incentive arises because some investors operate with constraints, such as fixed nominal rate targets tied to their liabilities, or asset managers have contractual arrangements in which their compensation is based on returns above a nominal level. For Treasury securities, looser monetary policy, combined with investor behavior, can lead to lower real term premiums for Treasury securities than can be justified by fundamentals. Hanson and Stein (2015) provide evidence that monetary policy shocks induce sizable effects on distant forward real rates, likely due to lower term premiums, which they show is consistent with yield-oriented investors who prefer current income to a holding-period return. When monetary policy loosens, these investors rebalance to longer-term bonds, so as to mitigate a decline in current yields, thereby boosting longer-term bond prices and reducing term premiums. This mechanism is similar to unconventional monetary policy, such as asset purchases of Treasury securities, which work by lowering term premiums. It represents a potential risk to financial stability if combined with leverage and maturity transformation.

Monetary policy also could lead to a compression of risk premiums by increasing risk-taking at financial institutions. In theoretical contributions, Allen and Gale (2000, 2004) provide models where bubbles in real estate prices can arise because of agency problems between investors and lenders (risk-shifting because lenders do not observe the risky investment), and as credit expands. Low interest rates can encourage investors to purchase a risky asset, boosting its current price. The expectation of future credit expansion will also raise current prices, though at the same time increasing the

likelihood of a future crisis. They argue that expectations about future credit are determined by monetary policy.

Adrian and Shin (2008) focus on the empirical relationship between monetary policy, asset prices, and financial intermediaries. Looser monetary policy increases the ability of intermediaries to take on leverage, which in turn affects the pricing of risk (see also Adrian, Moench, and Shin 2010 and Adrian, Etula, and Muir 2014). This evidence suggests that loose monetary policy fuels risk-taking, which in turn leads to a lower price of risk and lower contemporaneous risk. However, that compression in risk and the pricing of risk tends to increase forward-looking risk, as it fuels leverage due to lax risk-management constraints, giving rise to financial stability concerns as low risk premia and low volatility thus contribute to a buildup in imbalances, which is referred to as the “volatility paradox” (Brunnermeier and Sannikov 2014b).

Feroli et al. (2014) and Morris and Shin (2014) posit that unlevered asset managers who are evaluated based on their relative performance provide a channel for monetary policy to generate sharp rises in risk premia not related to changes in fundamentals. Loose monetary policy may lead to greater flows to funds that are managed by asset managers, who want to avoid being the worst performer since investors can redeem assets. Fund flows lead to increases in prices, generating momentum and a feedback loop between flows and prices. But when investors believe monetary policy may tighten, the aversion by asset managers to underperformance can create a sharp jump in risk premia. They document this channel for risky bonds, though they do not find empirical support in Treasuries or equities.³

Accommodative monetary policy in a setting with financial frictions can lead to sharper declines in prices in the event of adverse shocks than if risk premiums were constant or unrelated to those frictions. In addition, time-varying risk premia suggest that periods of compressed risk premia can be expected to be followed by a reversal of valuations (He and Krishnamurthy 2013). López-Salido, Stein, Zakrajšek (2016) test this hypothesis directly. Periods of narrow risk premiums for corporate bonds and high issuance of low-rated

³Even so, more work is needed to determine if the jumps in risk premia are sufficiently large to pose a threat to financial stability in the absence of high leverage and maturity transformation in the broader financial system.

bonds are useful predictors of negative investor returns in the subsequent two years, building on Greenwood and Hanson (2013). The negative returns in turn lead to a contraction in output, which likely is due to a pullback in credit supply. Their study provides direct evidence of an intertemporal tradeoff between accommodative current financial conditions at some future cost to economic output. In addition, Claessens, Kose, and Terrones (2012) show that recessions associated with house price or equity price busts tend to be both longer and deeper than other recessions. Their study analyzes forty-four countries from 1960 to 2010 and finds this pattern for both advanced and emerging economies.

3.3 Banking Sector

3.3.1 Financial Conditions

Besides its impact on asset valuations, monetary policy has traditionally been viewed to work through the banking sector, mainly as lower policy rates lead to an increase in the volume of lending (see Peek and Rosengren 2013 for a review). The bank lending channel posits that easier policy relaxes borrowing constraints of banks, shifting credit supply (Bernanke and Blinder 1988; Kashyap and Stein 1994). Bernanke and Blinder (1992), Kashyap, Stein, and Wilcox (1993), and Bernanke and Gertler (1995) provide empirical support for the bank lending and balance sheet channels, based on aggregate data, as monetary policy tightening lead banks to shrink lending. Kashyap and Stein (1995, 2000) show that banks that are small and less liquid, and have fewer margins to adjust to a loss of reservable deposits, reduce loans by more when policy tightens. While many studies support the lending channel, recent developments in financial markets, such as growth of securitization, suggest that the channel through banks may have become less of an amplification channel for monetary policy (Loutskina and Strahan 2009).

Capital requirements may influence the impact of monetary policy on bank lending. Peek and Rosengren (1995) show that an adverse capital shock that makes a capital constraint binding will cause banks to shrink assets and liabilities. When comparing capital-constrained to unconstrained banks, the unconstrained were more able to increase loans in response to an easing of policy.

3.3.2 *Financial Stability*

An increasing number of papers have focused on the link between the stance of monetary policy and the risk-taking behavior of banks, which increases vulnerabilities and risks to financial stability. Loose monetary policy can encourage banks to take on more risk on both the asset side and the liability side. On the asset side, banks can reach for yield (Rajan 2005), which will increase the share of risky assets. On the funding side, loose monetary policy increases incentives to use more short-term funding. Adrian and Shin (2010) and Stein (2012, 2013) show that increases in policy rates are associated with declines in short-term liabilities.

Recent papers provide cross-sectional evidence of the risk-taking channel, in which monetary policy affects not just the quantity but also the quality of credit. The risk-taking effects depend importantly on the amount of bank capital, where higher levels of capital mitigate incentives to reduce the quality of credit. Jiménez et al. (2012) use detailed credit register data in Spain to show that lower rates lead to greater risk-taking and more credit to riskier firms, and this effect is greater at banks with lower capital. Dell’Ariccia, Laeven, and Suarez (2013) look at this channel in the United States and find a relationship between ex ante riskiness of loans and bank capital. Paligorova and Santos (2017) evaluate loan spreads on syndicated loans in the United States and find that required spreads for more risky to less risky borrowers are lower in periods of looser monetary policy and are stronger for banks with greater risk appetite. Madaloni and Peydró (2011) find that low rates lead to softer lending standards in both the United States and the euro area, which is greater if rates have been low for an extended period, supervision is weaker, and securitization activity is greater. Altunbas, Gambacorta, and Marques-Ibanez (2010) show that unusually low rates for an extended period led to a sharper rise in expected default probabilities for banks, consistent with greater risk-taking.

Monetary policy also affects the leverage of financial institutions. Drechsler, Savov, and Schnabl (2014) model the effects of monetary policy by affecting the external finance spread that banks pay to leverage. Easing of monetary policy leads to lower leverage costs for banks, which increases risk-taking and lowers risk premia. They document that an external finance spread for banks (the funds rate – the

T-bill rate) moves closely with the federal funds rate. Adrian and Shin (2010, 2014) document that broker-dealer leverage is endogenous and highly procyclical, due to the way in which risk management is conducted. Adrian and Shin (2009, 2011) link the procyclical leverage to monetary policy, showing that tighter monetary policy tends to lower risk-taking of broker-dealers, leading to an increase in the pricing of risk, with associated contractionary macro consequences. In addition, Adrian, Moench and Shin (2010) link leverage management to aggregate economic activity, and show that shocks to dealer leverage impact macro activity through the pricing of risk. Adrian and Boyarchenko (2012) and Nuño and Thomas (2014) provide theories that rationalize these facts within dynamic stochastic general equilibrium (DSGE) models. In Adrian and Boyarchenko (2012), higher leverage is further associated with an increase in financial vulnerability in the form of systemic risk.

3.4 Shadow Banking

3.4.1 Financial Conditions

Shadow banking can be defined as maturity transformation, liquidity transformation, and credit risk transfer outside of institutions with direct access to government backstops such as depository institutions (see Adrian, Ashcraft, and Cetorelli 2013 for a recent overview). This intermediation takes place in an environment where prudential regulatory standards and supervisory oversight are either not applied or are applied to a materially lesser or different degree than is the case for regulated banks. The shadow banking system decomposes credit intermediation into a chain of wholesale-funded, securitization-based lending.⁴

⁴Shadow credit intermediation is performed through chains of non-bank financial intermediaries in a multi-step process that can be interpreted as a “vertical slicing” of the traditional banks’ credit intermediation process into seven steps. Pozsar et al. (2013) explain the seven steps of shadow bank credit intermediation in detail. The seven steps involve (i) loan origination, (ii) loan warehousing, (iii) pooling and structuring of loans into term asset-backed securities (ABS), (iv) ABS warehousing, (v) pooling and structuring of ABS into collateralized debt obligations, (vi) ABS intermediation, and (vii) funding in wholesale funding markets by money market intermediaries.

The shadow banking system transforms risky, long-term loans (mortgages, for example) into seemingly credit-risk-free, short-term, money-like instruments. The creation of money-like shadow bank liabilities complements traditional forms of money creation (Gorton and Metrick 2012). High-powered money can be created only by central banks. Commercial banks create broader forms of money, such as demand deposits. Shadow bank money creation occurs primarily in the commercial paper market and the repo market, and is funded by money market funds and short-term investment funds. Shadow bank liabilities can substitute for money in the private sector's asset allocation. Sunderam (2015) shows that shadow banking liabilities respond to money demand shocks. Gallin (2013) provides a comprehensive map of the amount of short-term funding from the shadow banking system to the real economy, based on the flow of funds statistics. Short-term money creation by the shadow banking system also furthers monetary policy transmission.

Money creation in the shadow banking system is at the root of the breakdown of monetary relationships in the United States. Until the early 1980s, the relationship between money growth and nominal output growth was very stable, a fact usually labeled the stable velocity of money. Schularick and Taylor (2012) document that credit began to grow rapidly and decouple from broad money since the early 1970s, via a combination of increased financial risk and leverage outside of non-monetary liabilities at banks. Since the shadow banking system became a quantitatively important contributor to credit intermediation, shadow bank money creation has led to a highly time-varying velocity of money. This reflects the feature of the shadow banking system that it responds quickly to changing financial, economic, and regulatory conditions.

3.4.2 Financial Stability

The shadow banking system, which is less constrained than banks by prudential regulation, leads to a greater transmission of monetary policy through a higher degree of endogenous risk-taking. The greater risk-taking may be evident in higher leverage, and greater maturity and liquidity transformation, allowing the system to operate at higher levels of risk-taking and increasing the potential for systemic financial crises (see, e.g., Brunnermeier and Pedersen 2009;

Geanakoplos 2010) The presence of shadow banking thus steepens the risk–return tradeoff relative to an economy with only traditional banking, making monetary transmission faster but also riskier.

A generic model of shadow bank intermediation that features such a steepening in the aggregate risk–return tradeoff has been proposed by Moreira and Savov (2013). Intermediaries create liquidity in the shadow banking system by leveraging up the collateral value of their assets. However, the liquidity creation comes at the cost of financial fragility, as fluctuations in uncertainty cause a flight to quality from shadow liabilities to safe assets.⁵

Per definition, funding sources for shadow banking activities are uninsured and thus runnable. In many ways, the fragility of shadow banks due to runnable liabilities resembles the banking system of the nineteenth century, prior to the creation of the Federal Reserve and the Federal Deposit Insurance Corporation. During that time, bank runs were common, and they often had severe consequences for the real economy. The shadow banking system’s vulnerability to runs bears resemblance to bank runs as modeled by Diamond and Dybvig (1983). Shadow banks are subject to runs because assets have longer maturities than liabilities and tend to be less liquid as well. Gorton and Metrick (2012) document the run on the shadow banking system at the beginning of the financial crisis of 2007–09, as investors began to question the value of subprime mortgage collateral. Covitz, Liang, and Suarez (2013) show that ABCP programs that held subprime mortgage securities were more likely to be run if they had weaker liquidity and credit support, as commercial paper investors are especially sensitive to being paid in full and on time. Moreover, for programs able to issue paper, spreads were wider and maturities were shorter, pointing out their inherent fragility and source of financial instability.

In a run, shadow banking entities have to sell assets at a discount, which depresses market pricing. Martin, Skeie, and von Thadden (2012) provide a model for a run in repo markets. In their model,

⁵ ABCP since 2004 was—at least in part—attributable to regulatory arbitrage triggered by a change in capital rules. Acharya, Schnabl, and Suarez (2013) document that the majority of guarantees were structured as liquidity-enhancing guarantees aimed at minimizing regulatory capital, instead of credit guarantees, and that the majority of conduits were supported by commercial banks subject to the most stringent capital requirements.

repo borrowers face constraints due to the scarcity of collateral and the liquidity of collateral. Under sufficiently adverse conditions, self-fulfilling runs can occur. Duarte and Eisenbach (2013) quantify repo runs and find large spillovers, with potentially systemic effects.

Another source of financial stability risk emanating from shadow banking is related to the perception of tail risk. Misperceived tail risk matters for monetary policy, as it affects estimates of downside risk to real activity and inflation. An early paper warning of the financial system's exposure to such tail risk was presented by Rajan (2005), who asked whether financial innovation had made the world riskier. Rajan (2006) later notes that financial intermediaries have incentives to show superior performance in periods when financing is ample, which leads them to take on tail risk. Shadow banking activity is often tailored to take advantage of mispriced tail risk, making the shadow banking system particularly sensitive to tail events. Such tail risk might be mispriced *ex ante*, either due to irrational or due to rational reasons. Gennaioli, Shleifer, and Vishny (2013) posit that actors neglect risk based on behavioral evidence. When investors systematically ignore the worst state of the world, overinvestment and overpricing during the boom and excessive collapse of real activity and the financial sector during the bust are generic features of shadow credit intermediation.

Coval, Jurek, and Stafford (2009) point out that the AAA tranches of private-label asset-backed securities behave like catastrophe bonds that load on a systemic risk state. Neglected risk also manifests itself through overreliance on credit ratings by investors. For example, Ashcraft et al. (2011) document that subprime MBS prices are more sensitive to ratings than *ex post* performance, suggesting that funding is excessively sensitive to credit ratings relative to informational content. Merrill, Nadauld, and Strahan (2014) show that life insurance companies with low capital that were exposed to unrealized losses in the early 2000s increased their holdings of highly rated securitized assets which offered higher yield per unit of required capital, reflecting perhaps neglected tail risks. In contrast, Chodorow-Reich (2014) finds only limited evidence of reach for yield behavior at financial institutions: for money market funds, the interaction of low nominal interest rates and administrative costs forced the funds to waive fees; funds with higher costs reached for higher returns in 2009–11, but not thereafter.

4. Macroprudential Policies

This review of papers provides considerable evidence that monetary policy affects the buildup of vulnerabilities—narrow risk premiums, excess credit at borrowers, and higher leverage and more fragile funding in the financial sector. However, adjustments to monetary policy to reduce these vulnerabilities may at times come into conflict with its primary mandates to achieve price stability and full employment.

Macroprudential policies can improve the intertemporal trade-off for monetary policy by preemptively lowering vulnerabilities of the financial system. For example, increasing capital requirements may reduce risk-shifting by insufficiently capitalized banks that leads to lower quality loans and increases vulnerabilities. Higher capital could be set through enhanced structural requirements, but may be more costly than a cyclical time-varying capital requirement, since it will remain at its constant high level at a credit-cycle peak, when investors and firms already are highly risk averse and reluctant to extend credit. However, decisions to implement cyclical policies raise difficult timing issues for policymakers, and may be subject to the criticism that macroprudential authorities are raising capital requirements to restrict credit by too much when future costs to financial stability are highly uncertain or that they are releasing capital too soon when concerns about bank default are still high.

Cyclical policies vary widely by their implementation costs: Relatively inexpensive actions include increased supervisory scrutiny targeted to specific firms and activities, communications by authorities, or public recommendations by financial stability coordinating or decision bodies (such as the Financial Stability Oversight Council in the United States or the Financial Policy Committee in the United Kingdom) to regulators, financial institutions, or market participations. At the other end of the cost spectrum, a countercyclical capital buffer could imply significant capital raising and international cooperation.

This section reviews the literature on cyclical macroprudential tools. Empirical evidence is mostly from emerging market economies, which may limit the insights for advanced economies with more complex financial systems, in which leakage of activities from the regulated to unregulated sectors can undermine the effectiveness of these tools. In addition, the governance framework

for implementing such tools may vary considerably, with fewer regulators in emerging market economies than in advanced economies. Table 3 summarizes existing macroprudential tools for each of these sectors.

4.1 Non-financial Sector

Macroprudential tools to address emerging imbalances in the non-financial sector aim primarily at improving underwriting standards to reduce borrower debt. For example, increasing loan-to-value (LTV) ratios or debt-to-income (DTI) ratios on mortgages can limit the exposures of households and businesses to a collapse in prices, thereby bolstering their resilience. Theoretical evidence on the effectiveness of LTVs is mixed. Goodhart et al. (2012) study LTV limits in conjunction with capital and liquidity regulations. In their model, LTV tools are relatively ineffective in the presence of asset price booms. One reason is that as the rise in asset prices boosts collateral values, it becomes relatively easier to satisfy LTV constraints. Bianchi and Mendoza (2011) find some welfare benefits of an LTV in a model that incorporates that borrowers will borrow more than socially optimal because they do not consider a debt deflation spiral arising from binding collateral constraints based on falling asset values. But they also find that a constant high LTV can be costly because once the deflation spiral occurs, the best outcome would be to relax the borrowing constraint and allow a higher LTV.

In cross-country empirical work, Kuttner and Shim (2013) provide evidence based on fifty-seven countries that limits on debt-service-to-income ratios can help to restrain housing credit, thereby moderating the cycle, while LTVs are less successful at restraining credit growth since credit can increase with real estate values. Cerutti, Claessens, and Laeven (2017) document the use of macroprudential policies for 119 countries over the 2000–13 period, covering many instruments. Borrower-based tools can lead to a reduction of growth in credit, notably in household credit. The effects are smaller in open economies, and usage comes with greater cross-border borrowing, suggesting some avoidance. This evidence suggests that macroprudential policies can help manage financial cycles by mitigating household credit growth.

Table 3. Macroprudential Policy Tools in Different Sectors

Sectors	Financial Stability	Macroprudential Tools
Non-financial Sector	Deterioration in underwriting standards Excess leverage • Fire-sale externalities • Negative demand externalities	Limits on underwriting standards, such as LTVs and DTIs Limits on adjustable-rate loans for borrowers, stress-test borrowers for rising rates
Asset Markets	Compressed risk premiums • Reach for yield because of nominal targets • Supported by leverage from an external finance premium, asymmetric information • Asset managers that prefer yield income or are evaluated based on relative performance Low volatility and low risk premiums • Procyclical risk-management practices • Mismeasurement of risk	Underwriting standards for debt, such as LTVs and DTIs Sectoral risk weights at banks Countercyclical capital or liquidity buffers Margins and haircuts Limits on short-term collateralized funding

(continued)

Table 3. (Continued)

Sectors	Financial Stability	Macroprudential Tools
Banking Sector	Procyclical leverage of banks and dealers • Procyclical risk-management practices and inflated collateral values Risk-shifting channel reduces the quality of credit • Low bank capital	Higher capital and liquidity requirements Countercyclical capital and liquidity requirements Sectoral risk weights Supervisory guidance, exposure limits Supervisory stress tests
Shadow Banks, Financial Markets	Procyclical dealer-intermediated leverage • Procyclical risk-management practices and inflated collateral values Excessive maturity transformation • Short-term funding fragilities Regulatory arbitrage	Reduce regulatory and accounting incentives to move activities from regulated sector Higher minimum haircuts or margins Tighter standards on securitizations

Because of significant differences across countries in financial system structures that could change the effectiveness of macroprudential tools, case studies may be a constructive analytical approach. In the United States, there is some evidence that the use of LTVs and maturity caps in the early 1950s, as imposed by the Federal Reserve Board, were effective in reducing housing starts, but Congress removed that authority, partly reflecting uneasiness with the Federal Reserve targeting particular types of credit growth (Elliott, Feldberg, and Lehnert 2013). In recent years, a number of countries have increased loan-to-value ratios on residential mortgages to limit an increase in exposures of households to a collapse in prices, and to lean against rising real estate prices. For example, Hong Kong has increased LTVs multiple times on residential mortgages in the past decade to mitigate the house price boom. As prices have continued to rise, they have also “stress-tested” borrowers for resilience to increases in interest rates. Korea imposed LTV and DTI limits on households, which appear to have reduced mortgage loans, housing transactions, and house prices in the six months after implementation. The Bank of Israel took several steps between 2009 and 2011 to rein in a housing boom, including a supplementary reserve requirement for banks’ mortgage loans with high LTVs, increased capital requirements for mortgages with floating rates and high LTVs, and restricting the adjustable interest rate component of mortgage loans. Canada has employed a mix of LTV and DTI restrictions, in addition to maturity caps and mortgage insurance limits, to restrain a buildup in household leverage and house prices. With time, the experience of these efforts will be important contributions to the profession’s understanding of these tools.

4.2 Asset Markets

Macroprudential tools could be used to lean against increases in asset prices or to mitigate risks from a subsequent downturn in asset prices, by tightening underwriting standards such as LTVs and DTIs. Other tools include countercyclical capital buffers, or higher risk weights or sectoral capital buffers for regulated firms. In addition, if asset prices are being fueled by leverage, standards could be tightened on implicit leverage through securitization or other risk transformations, or by limiting the debt provided to investors in

either unsecured or secured funding markets by raising margins and haircuts.

Empirical evidence of the effectiveness of macroprudential tools to lean against rising asset prices is scarce and limited to effects on house prices. Kuttner and Shim (2012) find that LTVs and exposure limits at financial institutions may help to reduce house price growth, using a sample of actions in fifty-seven countries. Looking at recent specific cases, the use of LTV limits combined with other actions in Hong Kong, Korea, and Canada may have mitigated some growth in house prices (Almeida, Campello, and Liu 2006; Igan and Kang 2011; Wong et al. 2011). Kuttner and Shim (2013) in a later study show for the same countries that low short-term interest rates contribute to house price increases and credit growth, but cannot account fully for the booms and busts. Dokko et al. (2009) show that monetary policy deviations from the Taylor rule explain only a small part of the rise in house prices in the United States leading up to the financial crisis.

To mitigate the consequences of an asset price boom and bust, the set of macroprudential tools available are basically designed to reduce leverage and unstable funding at financial firms and at borrowers.

4.3 Banking Sector

Macroprudential tools that could offset excessive risk-taking in banking include the new Basel III countercyclical capital buffer, which can be built up in boom times when the cost of equity is relatively cheap and deployed in downturns when the accumulation of capital is expensive. A buildup during extended boom times would result in a higher capital buffer, leaving banks better positioned to withstand large adverse shocks. A release of the countercyclical capital buffer in a downturn would offset pressures for banks to deleverage, thus mitigating the potentially adverse amplification of forced deleveraging during an economic downturn. In principle, the buildup and release of the buffer would be a function of the pricing of risk, whereas capital required for microprudential objectives would be a function of physical default risks.⁶

⁶The Federal Reserve issued for public comments a framework for implementing countercyclical capital buffers in December 2015.

A tool that is similar to countercyclical capital requirements, but that works in a more targeted fashion, is sectoral capital requirements. Sectoral capital requirements would be built and released like a countercyclical buffer, but higher or lower capital charges would be for specific asset classes.

Other policy tools include supervisory guidance and stress tests. Supervisory guidance, which could be used to signal a need to improve risk-management practices around potential future risks, is by design flexible and can be effective (Bassett and Marsh 2014). Supervisory stress tests can address emerging vulnerabilities by adjusting the severity of the macroeconomic and financial scenarios, in practice working to offset procyclicality inherent in capital regulations (Liang 2013). Stress tests can also highlight potential salient risks, such as a sharp rise in term premiums when interest rates have been low for an extended period. However, because excessive tightening of prudential regulations for banks can be expected to push financial intermediation into the shadow banking system, especially when the pricing of risk is low, macroprudential policies aimed at systemically important financial institutions (SIFIs) should be complemented by prudential policies for the shadow banking system.

Empirical evidence is limited, since traditional microprudential tools have not really been used to achieve broader financial stability. Higher bank capital ratios are found to reduce the probability of a crisis (Anundsen et al. 2014), and a Basel Committee on Banking Supervision (2010) study finds that higher capital requirements lower tail risk, but they also lower GDP growth for a number of years. Aiyar, Calomiris, and Wieladek (2016) use U.K. minimum bank capital requirements to estimate the impact of capital on credit supply and find that bank lending reacts substantially to capital requirement changes. However, Aiyar, Calomiris, and Wieladek (2014) find substantial leakage of capital regulation as foreign banks partially offset the impact of capital requirements on bank credit supply.

An alternative way to evaluate macroprudential tools is in the context of DSGE models. Analysis of macroprudential tools in the presence of banking frictions within equilibrium models is rapidly developing. For example, Kiley and Sim (2012) examine a setting where banks face an external finance premium. Modigliani-Miller is assumed to fail so that debt is cheaper than equity and outside equity is the most expensive form of funding. The key friction in

Kiley and Sim (2012) is the pecuniary fire-sale externality across banks, reflecting bank balance sheet problems. Kiley and Sim evaluate policies to lean against credit growth, against asset prices, and against loan spreads. In particular, they analyze a procyclical capital buffer (interpreted as a tax on leverage) aimed at closing the gap between private and social costs of bank debt. In their setting, policies for loan spreads work best. While Kiley and Sim feature a monetary policy rule, they do not look at the interaction of the monetary policy rule with the macroprudential instruments.

4.4 Shadow Banking

Regulatory capital and accounting rules in the pre-crisis period had created significant incentives for banks to shift assets off balance sheet into shadow bank special-purpose entities (SPEs). Since then, bank regulatory and accounting reforms have been adopted to restrict regulatory arbitrage. For example, Basel III reforms have increased the capital charge for providing explicit support to shadow banks, assuming a higher drawdown rate under the liquidity coverage ratio for credit and liquidity facilities, and the Financial Accounting Standards Board adopted new rules that require sponsors to consolidate many previously off-balance-sheet transactions. These reforms should help reduce shadow banking that is done for the purpose of regulatory arbitrage. That said, more stringent banking regulations could also increase incentives to move some activities away from banks, especially if demand for credit or for cashlike assets strengthens.

Macroprudential policy tools that affect shadow banking are not well defined, and are very heterogeneous across entities and activities (see Adrian 2014 for a review; see also Hanson, Kashyap, and Stein 2011). While shadow banking activities are often regulated for market conduct and market functioning, most shadow banking entities and activities are not subject to prudential regulation. As a result, the availability of macroprudential policies for shadow banking is limited, though there is an international effort under way to improve shadow banking regulation.⁷

⁷The Financial Stability Board, as directed by the G-20 leaders, has been developing policy recommendations to strengthen the oversight and regulation of

One possible tool to address procyclical incentives in secured funding markets, such as repo and securities (sec) lending, is minimum standards for haircut practices, to limit the extent to which haircuts would be reduced in benign markets. Margins and haircuts effectively set the maximum amount of leverage that borrowers can take. Margins and haircuts are set by exchanges, clearinghouses, broker-dealers, and counterparties. In practice, however, such margins and haircuts are set from a purely microeconomic risk-management perspective. Macroprudential considerations would promote higher through-the-cycle margins because they could materially reduce the ability of shadow banking participants to take on excessive leverage in expansions.

Goodhart et al. (2012, 2013) consider the impact of margin constraints on shadow banks, capital and liquidity requirements on banks, and loan-to-value limits on borrowers in a dynamic equilibrium setting. The presence of a shadow banking sector generates fire-sale externalities on the banking sector and the household sectors, as haircuts tend to rise in times of stress. Limiting shadow bank leverage by setting margins preemptively can mitigate this fire-sale externality, but comes at the cost of reduced credit intermediation in the boom. Goodhart et al. do not find countercyclical capital requirements on banks to be particularly useful at preempting systemic risk in the presence of shadow bank intermediaries, as the shadow banking system can arbitrage the increased capital requirement. Instead, the joint usage of countercyclical capital requirements and countercyclical margin setting can be more effective. However, a constraint on the effectiveness of capital and margin policies is the fact that collateral values increase in asset price booms, making capital constraints ineffective as a preemptive tool, though they are still useful as a prudential instrument. For preemptive purposes, Goodhart et al. find liquidity requirements to be more effective in constraining risk-taking. However, the tightness of liquidity requirements is tightly

the shadow banking sector. The set of proposals attempt to (i) limit the spillover of shadow banking risks to the banking sector, (ii) reduce or eliminate the first-mover advantage in U.S. money market mutual funds that makes them vulnerable to runs, (iii) assess and mitigate risks of other shadow banking entities, (iv) assess and align the incentives in securitization, and (v) dampen risks and the procyclical incentives in secured financing.

linked to the stance of monetary policy, and to safe asset availability more generally.

Stein (2012) studies central bank policies in the presence of shadow bank intermediation. In Stein's setting, shadow bank intermediaries create money-like short-term debt. Due to an externality, shadow banks issue too much short-term debt, creating excess vulnerability to financial crises. Stein points out that balance sheet policies of the central bank can be a useful complement to traditional monetary policy through open market operations, as balance sheet policies affect the value to the shadow banking system of issuing short-term debt, and hence regulate the magnitude of excess vulnerability in the shadow banking system.

5. Interactions between Macroprudential and Monetary Policies

Since the transmission channels for macroprudential and monetary policies are intertwined because they affect the same variables, consideration should be given to whether monetary policy should incorporate financial stability objectives.⁸ An early contribution by Bernanke and Gertler (1999) evaluates whether monetary policy should react to asset valuations. They argue for a flexible inflation-targeting regime that considers asset prices only to the extent that they affect the inflation–activity tradeoff. This view used to be accepted widely, especially with respect to equity market bubbles, as the burst of the late 1990s' tech bubble appeared to be successfully offset by easing monetary policy.

There were some exceptions to these arguments. Christiano, Motto, and Rostagno (2006) argue that monetary policy that focuses

⁸More broadly, a theory of the interdependence of macroprudential, fiscal, and monetary policies is provided by Brunnermeier and Sannikov (2011, 2014a, 2014b). Their "I Theory" stresses the importance of spillover effects that link price stability, financial stability, and fiscal stability, and the difficulties of separation of the stability concepts. For example, financial instability prompts financial intermediaries to shrink their balance sheets and create less inside money. Consequently, the money multiplier collapses and Fisher deflation pressure emerges. This increases the real value of banks' liabilities and worsens financial instability. Also, monetary policy redistributes wealth to the ailing sector by changing the relative value between government debt and money in order to stabilize the overall economy.

narrowly on inflation may inadvertently contribute to welfare-reducing boom-bust cycles in real and financial variables.⁹ The authors show that a policy of monetary tightening when credit growth is strong can mitigate such problems. In addition, Christiano et al. (2010) document that stock market booms tend to be accompanied by low inflation. As a result, interest rate rules that focus narrowly on inflation targets will destabilize asset markets and the broader economy. Interest rate rules should thus be adjusted for asset valuations, for example by allowing an independent role for credit growth, to reduce the volatility of output and asset prices.

More broadly, since the financial crisis, the New Keynesian literature has focused on incorporating credit supply into monetary policy models. Gertler and Kiyotaki (2010) develop a canonical framework to analyze credit market frictions and aggregate economic activity in the context of the 2007–09 crisis, augmenting Bernanke and Gertler (1989) and Bernanke, Gertler, and Gilchrist (1999) with a financial sector. Gertler and Kiyotaki (2015) add a banking sector that features bank net worth and liquidity mismatch, which gives rise to bank runs, as in Diamond and Dybvig (1983). Woodford (2010) proposes a Keynesian IS-LM model augmented with financial intermediary frictions, based on Curdia and Woodford (2010). In that setting, the financial intermediation friction gives rise to a state variable in addition to inflation and real activity. That state variable can be mapped into credit spreads (loan less policy rate), which in turn enters into the optimal monetary policy rule. Optimal policy thus is explicitly dependent on credit supply conditions. Woodford (2011) studies optimal monetary policy in a setting with financial crises and finds that inflation-targeting rules should consider explicitly the possibility of financial crises.

Gambacorta and Signoretti (2014) compare the performance of Taylor rules augmented with asset prices and credit supply, building on the setting of Curdia and Woodford (2010), with more standard rules with flexible inflation targeting. They find that even if financial stability is not an explicit target for monetary policy, monetary policy rules that respond to borrower balance sheets and credit supply in the presence of supply shocks result in a better tradeoff

⁹See Adrian and Shin (2006) and Gertler (2006) for related arguments.

for inflation and output stabilization. In particular, indicators of financial-sector leverage should directly enter into an augmented Taylor rule, and preemptive monetary policy enhances welfare.

Gilchrist and Zakrajšek (2011, 2012) evaluate monetary policy rules that augment the Taylor rule with a credit spread. They use a New Keynesian model, augmented with the standard Bernanke, Gertler, and Gilchrist (1999) financial accelerator mechanism, which is capable of producing the dynamics of the U.S. economy during the recent financial crisis. The benefits of a monetary policy rule that incorporates credit spreads arise as asset prices anticipate the beneficial effects of such a rule in mitigating the financial frictions. In a calibration of the model to U.S. data, the spread-augmented policy rule dampens the negative consequences of financial disruptions on real economic activity, while engendering only a modest increase in inflation. López-Salido, Stein, and Zakrajšek (2016) also suggest the importance of asset prices and credit supply conditions for the setting of monetary policy.

In practice, monetary policymakers may already be considering financial stability objectives to some extent, even if these objectives are not in their explicit mandates. For example, with a simple quadratic loss objective function, policymakers would minimize the square of the expected value of the gap between output and potential output, and the variance of output (Kocherlakota 2014; Stein 2014; see also Peek, Rosengren, and Tootell 2015). Financial stability risks are reflected in the variance term. When the gap is large with actual well below potential, the variance around output would have less weight in the objective function. Moreover, looser monetary policy might also reduce the variance term, by strengthening the balance sheets of borrowers and lenders.¹⁰ However, when the output gap is close to zero, financial stability considerations would have greater weight in reducing variance. In this situation, a tradeoff may emerge as accommodative policy to promote current economic growth could lead to a buildup of vulnerabilities that increases the variance of output or downside risks to output in the future. This formulation emphasizes that considering risks to financial stability is

¹⁰For example, in a financial crisis, the positive impact of looser policy on risk-taking can improve financial stability.

not inconsistent with the mandates of price stability and maximum employment.

Of course, the consideration of both financial conditions and financial stability in the conduct of monetary policy is not without possible costs. Conceptually, incentive problems between price stability and financial stability could arise if clear priorities are not set (Smets 2013). For example, ex post monetary policy easing in a credit bust to inflate away some of the debt overhang could generate an inflation bias. If there are political pressures to not lean too hard against the wind, or to not engage in sectoral credit allocation, central bank policymakers with responsibilities also for financial stability may have incentives to use monetary policy ex post, which can then risk price stability.

Several papers model the interaction of both macroprudential and monetary policy. In Farhi and Tirole (2009, 2012), financial intermediaries make private choices about leverage and maturity transformation, taking into account anticipated monetary policy responses. Loose interest rate policies increase the likelihood of future crises because they provide incentives for greater maturity mismatch because central banks ex ante cannot commit not to inject liquidity after a crash, leading to excessive risk-taking in the aggregate. Farhi and Tirole (2012) argue that preemptive macroprudential policies, such as limits on short-term debt or restrictions against hoarding liquidity at financial firms, would increase welfare, to offset incentives of firms to correlate their risks.

Korinek and Simsek (2016) consider the relative efficiency of macroprudential and monetary policies in a setting where borrowers do not take the negative aggregate demand externality of leverage into account, resulting in excessive risk-taking. Monetary policy is constrained at the zero lower bound, giving rise to a shortfall in aggregate demand. An interesting result of their model is that debt limits (or mandatory insurance) can improve welfare, while a rise in rates to reduce leverage could prompt a recession, and borrowers may want to borrow even more to smooth consumption. In addition, a rise in rates transfers wealth from borrowers to savers, providing another incentive to borrow. Thus, macroprudential policies are more efficient than monetary policies for reducing excessive leverage. Efficiency requires setting a wedge between borrowers' and lenders' relative incentives to hold bonds, whereas interest rate policies

create a different intertemporal wedge that affects all incentives equally.

Several models focus on the coordination of macroprudential and monetary policies. Angelini, Neri, and Panetta (2012) show that the benefits of coordinated policies are sizable for financial shocks, but macroprudential policies may add to volatility in the case of typical real supply shocks if they are not coordinated with monetary policy. Angeloni and Faia (2013) show that a combination of countercyclical capital and monetary policy to a positive productivity shock that leads to bank leverage can be welfare enhancing (see also Christensen, Meh, and Moran 2011). Kiley and Sim (2015), in a model with financial intermediaries and asset prices, find that monetary policy acting according to a simple rule reacting to financial imbalances may not improve welfare, and will depend on the source of the shock, which is difficult for policymakers to identify in real time. For example, tighter policy to respond to shocks at financial intermediaries might enhance welfare, but monetary policy to offset a rise in credit-to-GDP because of a positive technology shock would not. The combination of macroprudential and monetary policy can generally improve welfare in their setting.

In addition, monetary policy tightening can put financial institutions closer to default, resulting in risk-shifting incentives, leading them to take on more, not less risk. A theoretical setting that studies this risk-shifting effect is presented by Dell'Ariccia and Marquez (2013) and Dell'Ariccia, Laeven, and Marquez (2014).

While risk-shifting is theoretically possible in that setting, it is usually dominated by the first-order effect which links rising rates to lower risk-taking, when capital constraints are not binding. However, Landier, Sraer, and Thesmar (2011) investigate the lending behavior of New Century Financial Corporation, a large subprime lender in the run-up to the 2007–09 crisis, and find evidence of risk-shifting. As the Federal Reserve began tightening rates in 2004, the increase in rates led to a large, adverse shock in the value of the loan portfolio that New Century held for investment purposes. New Century reacted to this loss to the value of its assets by lowering underwriting standards and issuing deferred amortization mortgages. These loans were riskier and more sensitive to housing valuations, substantially increasing risk-taking. New Century's shareholders thus gambled for resurrection, as their equity value was

low, and their risk-taking incentives (due to limited liability) were large.

In summary, there is an expanding literature to address the question of whether and how monetary policy should consider financial stability. These models include financial frictions such as asymmetric information, which lead to effects of asset prices on collateral values and borrowing constraints, institutional investor sticky nominal return targets, financial firms' risk models and limited liability, and agency costs. Moreover, individual borrowers do not have incentives to take into account their effects on aggregate debt when they make their own private decisions. Such financial frictions can lead to a buildup of vulnerabilities and a more fragile financial system in the future that is more prone to amplify negative shocks and end badly for the economy. At the same time, there are costs to using monetary policy for financial stability. For example, consideration of financial stability could lead to an inflation bias, moral hazard, and welfare reductions because tighter policy is too late to stop a credit boom or it tries to stamp out credit growth that reflects technology gains rather than excessive borrowing. More research is needed, but there is considerable evidence to suggest that models for the conduct of monetary policy need to incorporate more financial-sector features—in particular, time-varying risk premia and risk-taking.

6. Cost-Benefit Analysis of Using Monetary Policy to Lean Against the Wind

We use Svensson's (2016) framework, which builds on Svensson (2014), to illustrate how adding the risk-taking channel of monetary policy through asset prices and borrower leverage could significantly change a cost-benefit calculation for the use of monetary policy to lean against the wind (LATW). Svensson has posted a spreadsheet for his cost-benefit analysis in a simplified two-state example and has invited alternative assumptions, though his own extensive sensitivity analysis based on a multi-period model is that none appear to overturn his conclusion that the costs of LATW policy exceed the benefits.¹¹ We use the two-state example since our primary

¹¹Svensson's spreadsheet is available at <http://larseosvensson.se/files/papers/svensson-simple-example-of-cost-benefit-analysis-of-leaning-against-the-wind-v3x.xlsx>. Note that the key assumptions in the spreadsheet that Svensson

aim is to highlight some key assumptions for the net cost calculation and to suggest that more research is needed on the estimated parameters.

The spreadsheet analysis is collapsed to two states—crisis and non-crisis. The analysis is to compute the costs and benefits of a LATW policy, defined as raising interest rates by 1 percent for four quarters, and compare the welfare costs of LATW unemployment outcomes with unemployment outcomes of an initial baseline path (when the unemployment gap is assumed to start at zero).¹² In this framework, LATW monetary policy works through traditional mechanisms by reducing credit and increasing unemployment. There are no asset prices or lender or borrower behavior in the model, so a higher monetary policy path does not raise risk premiums or rein in risk-taking. Consequently, LATW does not reduce the severity of a subsequent crisis—the size of the unemployment increase in the crisis state—and it reduces the probability of a crisis by only a minimal amount in his model.

In Svensson's analysis, the benefits of LATW are to reduce credit and then the probability of a crisis. He estimates that raising the policy rate (i) by 1 percentage point for four quarters leads to a decline in household credit, a maximum of 1 percent (as estimated from the Riksbank model). Because monetary policy is neutral in the long run with respect to credit, the level of credit rises back to baseline by the end of the forty quarters, with credit growth peaking at around sixteen quarters. Lagged two-year credit growth then is used to determine the probability of a crisis using estimates from Schularick and Taylor (2012). Based on peak credit growth, the probability of a crisis start is about 3 percent; and assuming the economy stays in a crisis for eight quarters, the probability of being in a crisis (p)

provides and that are used for these figures, in which he collapses the model to two states, will not capture the variation over time in the probability of a crisis. But in this model, credit is neutral with respect to monetary policy, so high growth rates are offset by low growth rates, suggesting that the probability of a crisis relative to baseline can be negative and offset by positives. The spreadsheet uses parameters from periods when it is possible for policy to reduce a probability of a crisis relative to baseline.

¹²Note that the terminology is crisis and non-crisis, but the model does not have a financial sector, so the two states could also be called recession and non-recession.

is 6 percent. The effect of a higher policy rate on the probability of a crisis (dp/di) is estimated to be -0.1 percent. That is, a higher policy rate i of 1 percentage point would reduce the probability of a crisis from 6.0 percent to 5.9 percent.

In terms of the costs of LATW, raising i by 1 percentage point leads to an increase in the unemployment rate ($dU_{L,N}$) in the non-crisis state by 0.5 percent (line 2 of table 4), relative to a change of 0 in the baseline ($dU_{B,N}$), line 1, where $dU_{i,j}$ is the increase in the unemployment rate where $i = L$ for LATW or B for baseline, and $j = C$ in the crisis state or N in the non-crisis state. The model assumes that the increase in the unemployment rate once a crisis occurs is 5 percent, regardless of whether or not policymakers choose LATW ($dU_{B,C} = dU_{L,C} = 5$ percent, lines 1 and 2). This assumption is critical: Policymakers receive no payoff in the form of a smaller rise in unemployment in a future crisis from choosing LATW policy. Below we illustrate the sensitivity of the expected cost and benefit estimates to alternative assumptions for the size of the unemployment increase in a future crisis state.

The expected welfare cost of LATW policy assuming that ($dU_{B,C} = dU_{L,C} = 5$) (shown in line 7) is the probability-weighted welfare cost from higher unemployment in a non-crisis state and higher unemployment in the crisis state. More generally, the expected welfare cost can be graphed as a function of alternative values of $dU_{L,C}$, the increase in unemployment under LATW policy in the crisis state relative to $dU_{B,C} = 5$. Specifically, point C on the expected cost line in figure 2 refers to welfare costs of 0.55 in the initial case.

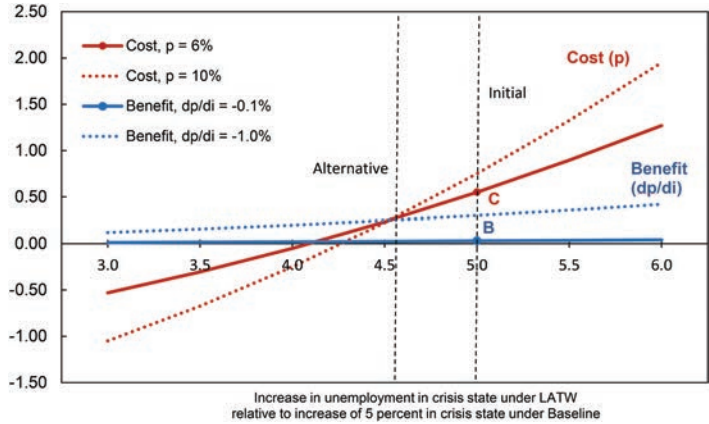
The expected benefit of LATW policy is also plotted, and point B (line 8 in the table) represents the initial case ($dU_{B,C} = dU_{L,C} = 5$). In this initial case, the expected benefits of .03 are considerably lower than the expected costs. With the parameters of the initial case, the increase in unemployment in the crisis under LATW would need to be 4.1 percent, about 0.9 percent lower than the assumed 5 percent, for the expected benefits of LATW to equal the expected costs.

Below we provide sensitivity analysis for three critical assumptions: (i) the rise in unemployment in a crisis; (ii) the probability of a crisis; and (iii) the elasticity of the probability with respect to a change in the policy rate.

Table 4. Estimated Costs and Benefits of LATW Policy in Svensson (2016) when the Unemployment Increase in a Future Crisis Is 5 Percent for Baseline and LATW

	Non-crisis State	Future Crisis State
(1) Baseline Unemployment (ppt)	$dU_{B,N} = 0$	$dU_{B,C} = 5$
(2) LATW Unemployment (ppt)	$U_{B,N} = 0.0$	$U_{B,C} = dU_{B,N} + dU_{B,C} = 5.0$
(3) Baseline Welfare Cost ($U_{B,j}^2$)	$dU_{L,N} = 0.5$	$dU_{L,C} = 5$
(4) LATW Welfare Cost ($U_{L,j}^2$)	$U_{L,N} = 0.5$	$U_{L,C} = dU_{L,N} + dU_{L,C} = 5.5$
(5) LATW Welfare Cost Increase Relative to Baseline (Line 4 – Line 3)	0	25
(6) Probability-Weighted Cost (for $p = .06$)	.25	30.25
(7) LATW Expected Cost	.25	5.25
(8) LATW Expected Benefit	$\begin{aligned} & [(1-p) * (U_{LN}^2 - U_{BN}^2) + p * (U_{LC}^2 - U_{BC}^2)] \\ &= .235 + .315 \\ &= .55 \\ &= -(dp/di) * [U_{LC}^2 - U_{LN}^2] \\ &= -(-.001) * [30.25 - .25] \\ &= .03 \end{aligned}$	$p * 5.25 = .315$

Figure 2. Welfare Costs and Benefits of LATW for Alternative Values of Unemployment Increase in a Future Crisis Relative to an Increase of 5 Percent in Baseline



6.1 Increase in Unemployment

Svensson assumes that the rise in unemployment even after LATW policy is still 5 percent. If we were to assume instead that LATW policy reduces credit and the severity of the crisis when it occurred, then costs of LATW policy would be lower. For example, as shown by the cost line (for $p = 6\%$ in baseline), if $dU_{L,C}$ is 4.5 percent (less than $dU_{B,C} = 5\%$), the costs of LATW policy would be .23, roughly half the costs when $dU_{L,C}$ is 5 percent. If the assumed rise were even smaller, if $dU_{L,C}$ were 4.0 percent, the costs of LATW policy would be negative, and net benefits would be positive. That is, the costs of LATW policy decrease substantially if the policy were to lead to reductions in the size of the increase in unemployment in a future crisis.

Benefits also vary positively with the increase in $dU_{L,C}$, but the slope is very small, reflecting the estimate that a rise in policy rate barely reduces the probability of a crisis. A smaller rise in unemployment in a crisis from LATW policy (4.5 percent rather than 5 percent) would reduce the benefits of LATW policy, but only by a little.

Svensson cites Flodén (2014) as an estimate of the effect of higher debt on the rise in unemployment. A 1 percentage point higher household debt-to-income ratio in 2007 results in an increase in unemployment during 2007–12 of 0.02 percentage point (indicating a decline of dU_C from 5 percent to 4.98 percent), a very small effect. Other empirical studies provide strong evidence that higher credit growth results in more severe recessions, suggesting that a smaller increase in unemployment from LATW policy is an alternative reasonable assumption. Unfortunately, most other studies have focused on the effects of credit growth rather than the level of credit on the severity of a recession, or the effect on output rather than unemployment. Flodén (2014) also looks at both the level and growth of credit, and finds they are both significant in explaining a subsequent decline in output, though only the level is a significant factor in the unemployment rate regression.

Jordà, Schularick, and Taylor (2013), in a study of fourteen countries with data starting in some cases in 1870, provide evidence that more excess credit growth in the period preceding a recession (relative to growth of the previous expansion) substantially increases the adversity of the subsequent recession, for both normal recessions and financial recessions (those with substantial losses to the banking sector). Their estimates show, for example, that in a normal recession, by the fourth year after the cyclical peak, the economy would be well into a recovery, with real GDP per capita estimated to be 3.8 percentage points higher than the cyclical peak. In the case of a financial recession, however, the economy would still not have fully recovered, with the GDP per capita level at –2.8 percentage points below the cyclical peak for average pre-recession excess credit growth. The strength of the recovery also depends on excess credit: in a normal recession, had credit exceeded average levels by one standard deviation, real GDP per capita would be lower by 1.8 percentage points, at 2.0 percent, and in a financial recession, real GDP per capita would be lower by 3 percentage points, at –5.8 percent, in the fourth year after the peak. While these estimates suggest significant effects for excess credit on lost output in the subsequent recession, it is difficult to convert their estimates to the effects of a 1 percentage point rise in the level of credit, given their measure of excess credit.

Mian, Sufi, and Verner (2015) also show that a steeper rise in household debt-to-GDP predicts higher unemployment and lower output over the medium term, based on data for thirty-four countries from 1960 to 2012. Specifically, they document that a one-standard-deviation increase in household debt-to-GDP growth in the three years before a cyclical peak leads to a 0.82 percent increase in the unemployment rate in the subsequent three years (and a decline in GDP growth of -2.1 percent). Their estimates imply that a 1 percentage point increase in credit growth in the three years before a cyclical peak would lead to a rise in unemployment of .13 percentage points and a decline in output of $-.37$ percentage points.

Sutherland et al. (2012) examine a sample of OECD countries from 1950 to 2010 and document that recessions occur twice as often and output declines during the recession are larger for high-debt versus low-debt levels (based on detrended debt to potential GDP). They also document that high debt levels lead to substantially greater volatility in output and consumption, and suggest that average effects miss an important cost dimension for households that are risk averse.

More recently, Gourio, Kashyap, and Sim (2016) model a tradeoff of LATW policy in a new Keynesian DSGE model. Their model highlights, as does Svensson (2016), that a tradeoff exists for a LATW policy relative to a policy based only on the output gap. They show that reduced credit comes at the expense of higher volatility in output and inflation, and then also highlight under what conditions welfare would be higher with a LATW policy despite the higher volatility. An interesting result is that if crises lead to permanent losses in output, which they argue are substantial, rather than just temporary losses associated with more typical business cycles, the benefits of LATW are greater. Their estimates of the severity of crises are measured as the gap between actual output and potential output at the onset of each crisis. They show that for the United States in the most recent crisis, this cost is 10 percent of output, despite the fact that the unemployment rate has almost returned to its natural rate.

While the research is growing, much more research is needed for robust estimates of the linkages from monetary policy to household and business credit, and then the effects of credit on the severity of a subsequent recession. Studies usefully have different samples,

but some focus on credit levels and others on credit growth, and what is viewed as average sustainable credit growth differs across the studies. What is clear is that debt levels in some expansions can become very high and the subsequent contractions can be more severe. But the differences in studies makes it difficult to settle on a single reliable estimate of the elasticity of unemployment or output to a change in credit.

Furthermore, broader financial conditions might be important conditioning variables for the severity of crises and hence for monetary policy. For example, Adrian, Boyarchenko, and Giannone (2016) show that the conditional GDP distribution depends significantly on financial conditions such as credit spreads, term spreads, and market volatility. In particular, such variables forecast sharp movements in the downside risks to GDP growth which should be taken into account in setting monetary policy even under flexible inflation targeting. Aikman et al. (2016) find that the non-financial credit-to-GDP gap is an important conditioning variable for economic activity, since the effects of financial conditions and monetary policy vary with the credit gap. Monetary policy is less effective when the credit gap is high, consistent with it being harder to stop a credit boom once one is under way and with a more muted transmission of the short-term policy rate to distant forward rates, in the spirit of Hanson and Stein (2015), who link the transmission of reductions in short-term policy rates to declines in forward rates and term premiums to the behavior of reach-for-yield investors.

6.2 *Probability of Crisis*

Another important parameter for the expected cost of LATW policy is the probability of a crisis. The estimations based on the sensitivity of household credit to interest rates in Sweden imply a probability of crisis start of 3 percent, about once every thirty years, and probability of being in a crisis of 6 percent (assuming weak growth for two years). In the United States, since 1975 there have been five recession starts (one in eight years), in which two (1990 and 2008) involved significant financial-sector stress.¹³ Based on these estimates of a

¹³The banking crisis that started in 1988 and includes the 1990 recession has also been labeled a financial crisis by Laeven and Valencia (2008). More than

crisis start of 5 percent, it is reasonable to evaluate the sensitivity of the costs of LATW policy if the probability of being in a crisis were 10 percent.

In figure 2, we show the expected cost curve if the probability of being in a crisis is 10 percent rather than 6 percent. The slope of the cost curve steepens significantly as a function of the crisis probability, and the costs of LATW policy fall below the benefits at around 4.3 percent, a less modest reduction in unemployment severity from LATW policy. That is, if the rise in unemployment were 4.3 percent, the costs of LATW policy become less than the benefits.

6.3 *Elasticity of Crisis Probability*

Given the very small benefits and the relative flatness to changes in assumed increases in unemployment in a crisis under LATW policy, we also explore the sensitivity of benefits to an increase in the elasticity of the probability of a crisis to a change in the interest rate. The proposed estimate of -0.1 is small (would reduce the probability from 6 percent to 5.9 percent). The current literature does not provide much guidance for alternative estimates of this elasticity. In fact, changes in credit growth from a change in monetary policy are typically evaluated in models that do not consider time-varying pricing of risk or endogenous risk-taking by financial intermediaries, and likely underestimate the sensitive of credit to monetary policy. We assume alternatives for the purpose of illustrating the sensitivity of the estimated benefits. For example, if $dp/di = -1$ for $p = 10\%$ (the light-gray dotted line, figure 2),¹⁴ the benefits of LATW are notably larger. For this parameter, if we assume again that the rise in unemployment under LATW policy is 4.5 percent, the benefits of LATW policy exceed the costs. Indeed, with this higher elasticity, LATW policy starts to yield positive net benefits when $dU_{LC} = 4.6\%$, shown by the vertical line labeled “Alternative.” That is, under alternative assumptions for the probability of a crisis and its sensitivity to a rise in the monetary policy rate, even a very small benefit in terms

1,400 savings and loans and 1,300 commercial banks failed during 1988–92, and the cost to the government amounted to \$180 billion, more than 3 percent of GDP.

¹⁴This line is shown as light blue in the online version, available at <http://www.ijcb.org>.

of a smaller rise in unemployment from LATW policy (a rise of 4.6 percent rather than 5.0 percent) would suggest that LATW policy has net benefits.

6.4 The Risk-Taking Channel in the Cost-Benefit Analysis

These observations support more testing of the sensitivity of the cost-benefit calculations to other estimates for the probability of crises and its sensitivity to monetary policy. The emerging research reviewed above suggests that models that do not incorporate the effects of monetary policy on endogenous risk-taking of borrowers or financial institutions would likely lead to an understatement of the sensitivity of probability of a crisis and the severity of a recession to monetary policy.

6.5 Implications of the Cost-Benefit Analysis

To summarize the sensitivity analysis, the result that costs exceed benefits relies critically on assumptions about the change in unemployment in a crisis, the crisis probability, and the elasticity of crisis probability with respect to the interest rate. For example, as illustrated by the calculations above, if the rise in unemployment in a crisis following a LATW policy was even just 4.6 percent rather than 5 percent, the conclusion that the costs of LATW policy would exceed the benefits would not hold. More research is needed to pinpoint the parameters for this cost-benefit calculation before applying the initial conclusion.

Of course, even if credit growth or risk-taking were amplifiers, it does not mean necessarily that monetary policy should target credit or risk-taking. Alternative tools, such as LTVs, DTIs, and bank capital, may be better suited to reduce excess credit because it can be more targeted. But in a complex advanced financial system with banks and non-bank financial intermediation, macroprudential policy may not be effective, because restrictions on regulated firms may push the activities into the unregulated sector.

7. Conclusion

The stance of monetary policy is transmitted to the real economy via multiple channels. In asset markets, the pure expectations channel is

complemented by a risk-taking channel, reflected by changes in the pricing of risk. These changes in the price of risk can be evident in asset markets, the banking sector, shadow banking, and non-financial-sector borrowers. As financial intermediation has become increasingly market based, the risk-taking channel has become more important, particularly in the shadow banking system, which relies principally on asset prices to support short-term funding. Risk-taking associated with expansionary monetary policy can cause the buildup of vulnerabilities that can generate systemic financial crises when adverse shocks hit.

Even if monetary policy were to contribute to the buildup of vulnerabilities—as both theory and empirics support—it does not mean that monetary policy should target these vulnerabilities. Most view macroprudential policies as the first-order defense against such buildups of vulnerabilities. However, macroprudential policies only directly affect a limited set of financial institutions due to shadow banking, have limited international reach, and are potentially subject to long implementation lags. Monetary policy, on the other hand, affects funding conditions for all intermediaries, more immediately, and has some global reach. Cost-benefit analysis of the use of monetary policy that does not incorporate the role of asset prices and credit may not be robust. While these arguments may lead to a conclusion that is uncomfortable because of the higher burden on monetary policy, cleaning up after the bust has proven in the long wake of the Great Financial Crisis to be extremely costly. More research is needed to evaluate the efficacy of macroprudential and monetary policies, independently and jointly, to prevent the buildup of vulnerabilities and to mitigate the consequences of busts on the real economy.

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Optimality of the Friedman Rule in Economies with Money Demand by Firms*

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Motivated by the facts that firms hold about two thirds of M1 in industrialized economies, I study the optimality of the Friedman rule in economies with money demand by firms and different types of fiscal instruments. Money demand by firms is introduced in two ways: a cash-in-advance (CIA) constraint on wages and money in the production (MIP) function. In the case of a CIA constraint on wages, I show that the Friedman rule is not optimal when the government has access to only one distortionary tax to finance its expenditures. This is the case both in an economy with labor only and in one with labor and capital. Once a sufficiently rich menu of taxes is available to the fiscal authorities, the Friedman rule, then, may or may not be optimal. In contrast, in the case of MIP function, the optimal policy is to satiate the economy with real balances, even in the presence of distorting taxes on consumption and capital. That is, the Friedman rule is optimal. I also show that adding a working capital constraint on wages to a cash-and-credit goods model has no impact on the optimality of the Friedman rule and that it still remains optimal if preferences satisfy homotheticity and separability assumptions.

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1. Introduction

“Our final rule for the optimum quantity of money is that it will be attained by a rate of price deflation that makes the nominal rate of interest equal to zero,” Friedman (1969) wrote in “The Optimum Quantity of Money.” By setting money growth at a rate that causes a deflation equal in magnitude to the real rate of return to physical assets, the central bank can make the return to holding money equal to the return to holding bonds. With that rate of deflation, the nominal interest rate is zero. The intuition for the Friedman rule is that because the marginal cost of creating additional money is zero, the opportunity cost of holding money, the nominal interest rate, faced by private agents should be zero. The main criticism to the Friedman rule is attributed to Phelps (1973). Phelps noted that analyzing inflation tax without consumption and labor supply functions is as if “professor Friedman has given us Hamlet without a prince.” In a public finance context and a general equilibrium model where inflation tax is optimally treated like other distortionary taxes, Phelps counterargued the optimality of the Friedman rule in favor of a positive rate of inflation. Following Phelps, a large literature that tried to analyze the optimal inflation rate in different models from different points of view emerged.

In most of this body of work that studied the optimality of the Friedman rule, one motivates the existence of a liquidity premium by supposing that households obtain a service flow from cash balances. Realistically, it is not only households that have motivation to hold cash balances, but firms as well. Important to emphasize is that in these frameworks where the attention is restricted to the case in which money is held only by households, variations in the nominal interest rate affect real variables solely through their effect on aggregate demand. This paper departs from the existing literature by studying the optimality of the Friedman rule in the context of models with demand for money by firms only and by both firms and households and with different types of distorting taxes. Considering a money demand by firms is motivated by the facts that a substantial part of M1 is held by firms. For example, the Federal Reserve’s (1988) Demand Deposit Ownership Survey (DDOS) surveyed changes over the 1980s in the shares of demand deposits. According to the DDOS, consumers held one-third of

demand deposits at all insured commercial banks in 1980. This share had declined to about one-quarter by 1987, while holdings of demand deposits by financial and non-financial businesses rose from three-fifths to about two-thirds of total demand deposits.¹ Also, Mulligan (1997) estimates a model of the demand for money by firms using longitudinal data on sales, money holdings, and other variables at the firm level. He shows, using Compustat data on 12,000 firms for the years 1961–92, that in industrialized economies about two-thirds of M1 are held by firms. Also, a large literature in finance documented a very significant increase in cash holdings by firms during the recent years.² It is therefore natural to motivate a demand for money by firms and study the optimality of the Friedman rule under this motivation. My purpose in this paper is to pursue this line of reasoning. The focus is to investigate whether the policy conclusion arrived at by the existing literature regarding the optimality of the Friedman rule is robust with respect to a more realistic specification of the economic environment, that is, where firms have motivations to hold money.

To do so, I consider monetary economies models, somehow similar to the models described in Chari, Christiano, and Kehoe (1996) and Schmitt-Grohé and Uribe (2004). Specifically, I build models to study the optimality of the Friedman rule in a stochastic, flexible-price, production economy without and with capital, where sources of inefficiency in the models stem from the nominal frictions of the demand for cash balances by firms and households and distortionary taxes. I first study the optimality of the Friedman rule in economies with money demand by firms only and then study this optimality in the cash-and-credit goods model of Chari, Christiano, and Kehoe (1996), with an added demand for real balances by firms. I rationalize money demand by firms by assuming that wage payments are subject to a cash-in-advance constraint and by assuming money in the production function. The first one is a very common assumption in the literature (see, e.g., Schmitt-Grohé and Uribe 2005, 2007

¹The Federal Reserve surveys for years prior to this period also show that a substantial part of M1 was held by firms. The Federal Reserve discontinued the DDOS in 1990.

²See, for example, Almeida, Campello, and Weisbach (2004), Ferreira and Vilela (2004), Han and Qiu (2007), Bates, Kahle, and Stulz (2009), and Gao, Harford, and Li (2013), among many others.

and, for a review, Christiano, Trabandt, and Walentin 2010). For the second one, I follow Benhabib, Schmitt-Grohé, and Uribe (2001, 2002) and assume that money affects production possibilities.

In a monetary economy where a fraction of wage payments is subject to a cash-in-advance constraint, I show that the Friedman rule is not optimal in the presence of distortionary taxes on consumption or labor income. This non-optimality of the Friedman rule recalls Phelps's criticism that Friedman's first-best argument ignores the second-best fact that inflation produces seigniorage incomes for the fiscal authority and all forms of taxation produce distortions of some kind. More precisely, it is no longer optimal to put the nominal interest rate equal to zero when the government has no access to lump-sum taxes and only to one distorting tax. Put another way, the optimal way to deal with a distortion depends on other existing distortions. When the government has access to taxes on both consumption and labor income, I show that the optimal policy is not unique and in fact there are a variety of policies that can implement the optimal allocation. Some of these have the optimality of the Friedman rule, but others do not. I also show that adding capital to the model and imposing taxes on it do not change the main result on the optimality of the Friedman rule. Again, as long as the fiscal authority doesn't have access to a rich menu of taxes and can only impose distortionary taxes on capital and labor income or capital and consumption, the Friedman rule ceases to be optimal. In the presence of a rich menu of taxes—that is, the distortionary taxes on capital, consumption, and labor income—the Friedman rule may or may not be optimal.

I then analyze the optimality of the Friedman rule in the context of a model where the demand for money is motivated by assuming that real balances facilitate firms' production. Specifically, I follow Benhabib, Schmitt-Grohé, and Uribe (2001, 2002) in assuming that money enters in the production function and affects production possibilities. In this context, in sharp contrast to the case of a working capital constraint on wages, the Friedman rule, even with distorting taxes on consumption and capital, emerges as the only possible solution to the Ramsey allocation problem.

I also study the optimality of the Friedman rule in the case of money demand by both households and firms. I consider a cash- and credit-goods model where cash goods and wage bill both are subject

to a cash-in-advance constraint. Chari, Christiano, and Kehoe (1996) in the cash- and credit-goods economy of Lucas and Stokey (1983) show that if preferences are homothetic in cash and credit goods and separable in leisure, then the Friedman rule will be optimal even in the presence of distorting taxes. I show that their conclusion remains the case even if wage payments are also subject to a cash constraint. While the presence of the demand for money by households calls for the optimality of the Friedman rule, the presence of the working capital constraint calls for the optimality of deviating from it. However, this tradeoff that the Ramsey planner faces between using inflation as a tax and minimizing the opportunity cost of holding money (which requires setting the nominal interest rate equal to zero) is resolved in favor of the Friedman rule. The reason is that with homotheticity and separability conditions, as proved by Chari, Christiano, and Kehoe (1996), the monetary economy can be reinterpreted as a real intermediate-goods economy, where—based on the standard public finance result—the optimal tax rate on an intermediate good is zero. Therefore, a positive interest rate means that the cash good is effectively taxed at a higher rate than the credit good, which is not optimal. This will also be the case with a cash constraint on wage payments.

The only papers, to the best of my knowledge, that directly address the optimality of the Friedman rule in a model with a money demand by firms are Faig (1991) and Schmitt-Grohé and Uribe (2005). Faig (1991) studied the optimality of the Friedman rule in a simple one-period static model where the transactions activity is performed by firms. Schmitt-Grohé and Uribe (2005) study Ramsey-optimal monetary and fiscal policy in a medium-scale macroeconomic model with several real and nominal rigidities. They numerically find that under an income tax regime and in the presence of a cash-in-advance (CIA) constraint on wage payment, even in the case of fully flexible prices, the Friedman rule ceases to be optimal. The reason, in their context, is that the Ramsey planner would like to tax capital and labor income differently but the income tax does not allow that, hence the inflation tax can be used as an indirect tax on labor.

The rest of the paper is organized as follows. Section 2 considers the optimality of the Friedman rule in a model with a CIA constraint on wages and different tax instruments, and section 3 presents the

same environment and the Ramsey problem with capital accumulation and capital taxation. Section 4 studies the optimality of the Friedman rule in an economy with money in the production function. Section 5 establishes that the Friedman rule in a cash-credit goods model with a CIA constraint on wages still remains optimal if the utility function is homothetic in consumption goods and separable in labor effort. Section 6 concludes.

2. A Model with a CIA Constraint on Wages, with Distorting Taxes, and without Capital

This section develops an infinite-horizon production economy with perfectly competitive product markets and flexible prices. A demand for money by firms is motivated by assuming that a fraction of wage payments is subject to a cash-in-advance constraint. The government finances an exogenous stream of purchases by printing money, imposing distorting taxes on labor income, or consumption, or both, and issuing one-period nominally risk-free bonds. I analyze the optimality of the Friedman rule in three different cases: first, the case that the only fiscal instrument is labor income tax; second, the case that the only fiscal instrument is consumption tax; and third, once the fiscal instruments are both consumption and income taxes.

2.1 Households

The economy is populated by a continuum of identical households that consume different varieties of goods, save, and work, and their preferences are defined over consumption, c_t , and labor effort, h_t . The representative household seeks to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, h_t), \quad (1)$$

where E_0 denotes the mathematical expectations operator conditional on information available at time zero and β is the subjective discount factor. The utility function U is strictly concave and satisfies the Inada conditions.

The flow budget constraint of the household in period t reads as follows:

$$P_t c_t (1 + \tau_t^c) + B_t = P_t w_t h_t (1 - \tau_t^h) + R_{t-1} B_{t-1} + \Pi_t, \quad (2)$$

where households are assumed to invest in non-state-contingent nominal bonds, B_t , which pay a nominal interest rate R_t one period later. τ_t^c is the distorting tax on consumption, τ_t^h is the distorting tax on labor income, w_t is the real wage rate, and Π_t are profits received from firms. Households are also assumed to be subject to a borrowing limit that prevents them from engaging in Ponzi schemes.

The representative household chooses the set of processes $\{c_t, h_t, B_t\}$, taking as given the set of processes $\{P_t, w_t, R_t, \tau_t^c, \tau_t^h\}$ so as to maximize utility (1) subject to the budget constraint (2). The first-order conditions are

$$U_c(c_t, h_t) = \lambda_t (1 + \tau_t^c) \quad (3)$$

$$U_h(c_t, h_t) = -\lambda_t w_t (1 - \tau_t^h), \quad (4)$$

$$\frac{\lambda_t}{P_t} = \beta R_t E_t \frac{\lambda_{t+1}}{P_{t+1}}, \quad (5)$$

where λ_t refers to the Lagrange multiplier on equation (2).

The interpretation of these equilibrium conditions is as follows: equation (3) states that the distortionary consumption taxes distort the equality between the marginal utilities of consumption and wealth. Equation (4) shows the equality between marginal utility of leisure and the marginal utility of labor income that is distorted due to the presence of labor income taxes. Equation (5) is the Euler condition with respect to bonds.

2.2 Firms

Firms use labor to produce consumption goods. One unit of labor is assumed to produce one unit of good which is perishable. Firms' money holdings are motivated by assuming that a fraction of wage payments is subject to a cash-in-advance constraint of the form

$$\gamma w_t h_t \leq m_t, \quad (6)$$

where $m_t = \frac{M_t}{P_t}$ is the demand for real money balances by firms in period t and M_t denotes nominal money holdings. γ is a parameter between zero and one, $0 < \gamma \leq 1$, and stands for the fraction of the wage bill that must be backed with cash.

The period-by-period budget constraint that the firm faces is

$$M_t = M_{t-1} + P_t h_t - P_t w_t h_t - P_t \Pi_t. \quad (7)$$

The firm chooses $\{h_t, M_t\}$ to maximize the present discounted value of profits, given by

$$\Pi_t = E_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \frac{1}{P_t} \{P_t h_t - P_t w_t h_t + M_{t-1} - M_t\} \quad (8)$$

subject to equation (6).

Here, $\beta^t \frac{\lambda_t}{\lambda_0}$ is the period-0 value to the representative household of period- t goods, which the firm uses to discount profit flows because households are the ultimate owners of firms.

This maximization gives the following first-order condition:

$$\frac{1}{w_t} = 1 + \gamma(1 - R_t^{-1}). \quad (9)$$

As is clear from equation (9), the presence of working capital constraint distorts the equality between the marginal product and the real wage of labor. When $R_t > 1$, the labor wage is less than its marginal product. In fact, the financial cost of labor is increasing in the opportunity cost of holding money, $1 + \gamma(1 - R_t^{-1})$, which is an increasing function of nominal interest rate.

2.3 The Government

The budget constraint that the government faces is given by

$$M_t + B_t + P_t \tau_t^c c_t + P_t \tau_t^h w_t h_t = R_{t-1} B_{t-1} + M_{t-1} + P_t g_t. \quad (10)$$

The consolidated government issues one-period nominally risk-free bonds, B_t ; prints money, M_t ; imposes distortionary taxes, τ_t^h and τ_t^c ; and faces a stream of public consumption, denoted by g_t .

2.4 Competitive Equilibrium

Absent arbitrage opportunities in equilibrium implies that $R_t \geq 1$. This in turn implies that, based on equation (9), in equilibrium $1 \geq w_t$ must hold.

A competitive equilibrium is a set of plans $\{c_t, h_t, M_t, B_t, w_t, \lambda_t, R_t, P_t\}$ satisfying equations (3), (4), (5), (6), (9), (10), and

$$R_t \geq 1, \quad (11)$$

$$U_c(c_t, h_t)(1 + \tau_t^c) \geq U_h(c_t, h_t)(1 - \tau_t^h), \quad (12)$$

$$c_t + g_t = h_t, \quad (13)$$

given policies $\{R_t, \tau_t^c, \tau_t^h\}$ and the initial condition $R_{-1}B_{-1} + M_{-1}$.

Equation (12) results from the non-negativity of nominal interest rate and equation (13) shows the real resource constraint.

2.5 Non-optimality of the Friedman Rule with Distortionary Taxes on Labor Income

I first eliminate the consumption tax from the menu of taxes available to the government and study the optimality of the Friedman rule in the version of the model in which the menu of fiscal policies is restricted to only labor income taxes. I then consider the case of consumption taxes only and, after that, both taxes together.

With income taxes only, the Ramsey-optimal policy is the process $\{\tau_t^h, R_t\}$ associated with the competitive equilibrium that yields the highest level of utility to the representative household. We know that if the initial financial wealth held by consumers is positive, the welfare is maximized by increasing the initial price level to infinity. To avoid this feature, I restrict the initial price level to be given.

Now I begin by deriving the primal form of the competitive equilibrium and then I state the Ramsey problem and show that the Friedman rule is not optimal.

2.5.1 The Primal Form

The problem of determining the optimal structure of prices and taxes to finance a given level of expenditures is called the Ramsey problem, after the classic treatment of Ramsey (1928). In

the representative-agent models, like the one studied here, the Ramsey problem is to maximize the utility of the representative agent subject to the government's revenue requirement.

There are two approaches to solve this problem. The first approach, often called the dual approach, employs the indirect utility function to express utility as a function of the government's control variables. The second approach, called the primal approach, which is considered here, involves the elimination of all prices and tax rates from the equilibrium conditions, so that the resulting reduced form involves only real variables. The primal form of the equilibrium conditions consists of two equations. One equation is a feasibility constraint, given by the resource constraint (13), which must hold at every date and under all contingencies. The other equation is a single, present-value constraint known as the implementability constraint (I do not present the derivation of the implementability constraint here, because it can be found in detail in both Chari, Christiano, and Kehoe 1991 and Schmitt-Grohé and Uribe 2004).

PROPOSITION 1. *Plans $\{c_t, h_t\}_{t=0}^{\infty}$ satisfying*

$$E_0 \sum_{t=0}^{\infty} \beta^t [U_c(c_t, h_t) c_t + U_h(c_t, h_t) h_t] = A_0 \frac{\lambda_0}{P_0}, \quad (14)$$

$$U_c(c_t, h_t) \geq U_h(c_t, h_t) (1 - \tau_t^h), \quad (15)$$

and equation (13), given $A_0 = (M_{-1} + R_{-1}B_{-1})$, $\lambda_0 = U_c(c_0, h_0)$, and P_0 , are the same as those satisfying equations (3), (4), (5), (6), (9), (10), (11), and (13).³

The real variables that appear in the primal form are consumption and labor effort. Equation (14), which is the present-value implementability constraint, is the government budget constraint expressed in intertemporal form with all prices and taxes substituted out using equilibrium conditions.

³It is worth noting that the primal form derived above doesn't depend on the value of γ . This means that the analysis remains the same if we allow for 100 percent cash in advance on the wage bill, that is, $\gamma = 1$.

PROPOSITION 2. *The Friedman rule in a model without capital and with a cash-in-advance constraint on wage payments and distortionary taxes on income is not optimal.*

Proof. The Ramsey planner maximizes the representative household utility (1), subject to equations (13) and (14).⁴

Let ψ_t and φ denote, respectively, the Lagrange multipliers on the feasibility constraint, (13), and the implementability constraint, (14).

The first-order conditions of the Ramsey planner's problem are

$$\begin{aligned} \frac{\partial L}{\partial c_t} &= U_c(c_t, h_t) + \varphi U_{hc}(c_t, h_t) h_t + \varphi U_c(c_t, h_t) \\ &\quad + \varphi U_{cc}(c_t, h_t) c_t - \psi_t = 0, \end{aligned} \quad (16)$$

$$\begin{aligned} \frac{\partial L}{\partial h_t} &= U_h(c_t, h_t) - \varphi U_{hh}(c_t, h_t) h_t + \varphi U_h(c_t, h_t) \\ &\quad + \varphi U_{ch}(c_t, h_t) c_t + \psi_t = 0. \end{aligned} \quad (17)$$

After rewriting equations (16) and (17), we get the following expressions:

$$(1 + \varphi) + \varphi \left(\frac{U_{cc}(c_t, h_t) c_t + U_{hc}(c_t, h_t) h_t}{U_c(c_t, h_t)} \right) = \frac{\psi_t}{U_c(c_t, h_t)}, \quad (18)$$

$$(1 + \varphi) + \varphi \left(\frac{U_{ch}(c_t, h_t) c_t + U_{hh}(c_t, h_t) h_t}{U_h(c_t, h_t)} \right) = \frac{-\psi_t}{U_h(c_t, h_t)}. \quad (19)$$

As is quite clear, the optimality conditions of the Ramsey problem do not imply the optimality of the Friedman rule. This is because, based on equations (3), (4), and (9), the Friedman rule $R_t = 1$ is optimal only if $U_c(c_t, h_t) = U_h(c_t, h_t) (1 - \tau_t^h)$. This cannot, however, be concluded from the above Ramsey optimality conditions.

Thus we conclude that in a model with cash constraint for firms and in the presence of distortionary taxes on income, the Friedman

⁴I focus on the less-constrained problem, that is, on the case in which the constraint (15) is dropped. If the Friedman rule is not optimal in the less-constrained problem, it will not also be optimal in the more-constrained problem.

rule is not optimal. The basic intuition for this conclusion recalls the result due to Phelps (1973). Phelps, in a model with money in the utility function and distorting labor income taxes, shows that the Friedman rule is not optimal, because inflation produces seigniorage revenues for the government. More precisely, instead of just making one of the distortions equal to zero and only using the other one, it is optimal to equalize the marginal distortion caused by one unit of revenue collected with distortionary income tax with the marginal distortion caused by one unit of revenue collected with inflation tax. This can be shown to be the case if, instead of distorting income taxes, the government has access to only distortionary taxes on consumption. I turn to this task next.

2.6 Non-Optimality of the Friedman Rule with Distortionary Taxes on Consumption

Instead of assuming distortionary taxes on labor income, now suppose that the government can impose distortionary taxes only on consumption at rate τ_t^c . That is, we now set τ_t^h to zero and allow τ_t^c to vary. The primal form of the equilibrium conditions in this case is essentially the same as the one associated with the economy with distortionary income taxes, proposition 1, except that equation (12) now changes as follows:

$$U_c(c_t, h_t)(1 + \tau_t^c) \geq U_h(c_t, h_t). \quad (20)$$

Since having access to distortionary consumption taxes doesn't change the primal form of the competitive equilibrium, the Ramsey problem remains the same. Thus, we can conclude that in this case also the Friedman rule ceases to be optimal. The reason is that with distortionary taxes on consumption, the Friedman rule would be optimal only if $U_c(c_t, h_t)(1 + \tau_t^c) = U_h(c_t, h_t)$ holds. However, as in the case with labor income taxes, we cannot conclude this equality from equations (18) and (19).

2.7 The Friedman Rule with Distorting Taxes on Consumption and Labor Income

Suppose now that there is a sufficiently rich menu of taxes available to the fiscal authorities. In other words, instead of assuming only

one distortionary tax, the fiscal authority now has access to both distortionary taxes on consumption and labor income. The primal form of the competitive equilibrium with taxes on both consumption and labor income is again the same as the primal form presented in proposition 1, with the exception that prices now should be expressed in terms of the consumer price gross of consumption taxes, $P_t^c = (1 + \tau_t^c) P_t$, where P_t , like before, is the producer price. In this case, the Ramsey allocation for each allocation $\{c_t, h_t\}_{t=0}^\infty$ is

implemented with a unique path for $\left\{ \frac{(1-\tau_t^h)}{(1+\tau_t^c)(1+\gamma(1-R_t^{-1}))}, w_t \right\}_{t=0}^\infty$.

There is a unique path for $P_t^c = (1 + \tau_t^c) P_t$ given P_0^c , and a unique path for $\{M_t, B_t\}_{t=0}^\infty$, but for each implementable allocation there are multiple fiscal policies consistent with it. More precisely, the individual tax rates, τ_t^c and τ_t^h , and the nominal interest rate, R_t , are not uniquely determined by the Ramsey allocation, so there are multiple fiscal and monetary policies that can implement that allocation. Some of those policies support the optimality of the Friedman rule, $R_t = 1$, but others do not. The reason is that for an implementable allocation $\{c_t, h_t\}_{t=0}^\infty$ in the set defined by the resource constraint (13) and the implementability conditions, (12) and (14), the three variables τ_t^c , τ_t^h , and R_t are restricted by only two restrictions, $\frac{(1-\tau_t^h)}{(1+\tau_t^c)(1+\gamma(1-R_t^{-1}))}$ and $(1 + \tau_t^c) P_t$. Therefore among the set of optimal taxes there could be a subset where the nominal interest rate is zero. In terminology of public finance, the three taxes are equivalent. Thus with taxes on consumption and labor income, there is not a unique path for R_t , and so the Friedman rule may or may not be optimal.

3. The Model with Capital

In the previous section I used a monetary model without capital and with a cash-in-advance constraint on wages to argue that the Friedman rule is not optimal whenever the government, to finance its expenditures, raises revenue either by taxing consumption or by taxing labor income. Here, I show that this basic result extends to a generalized version of the previous model in which I allow for capital accumulation and capital taxation.

3.1 Households

As above, households draw utility from consumption goods, c_t , and disutility from labor, h_t , based on equation (1). The household's budget constraint with capital can be written as

$$(1 + \tau_t^c) c_t + k_{t+1} + \frac{B_t}{P_t} = w_t h_t (1 - \tau_t^h) + [(1 - \delta) + (1 - \tau_t^k) u_t] k_t + \frac{R_{t-1} B_{t-1}}{P_t} + \Pi_t, \quad (21)$$

where k_t is capital, u_t is the real rental rate of capital, δ is the depreciation rate, and τ_t^k is the rate of tax on capital income.

The household's problem is to maximize lifetime expected utility, given by equation (1), subject to the budget constraints given by equation (21), provided that the no-Ponzi-game borrowing limit is satisfied.

The first-order conditions of the household's problem are equations (3), (4), and (5), the same as in the previous section, and

$$\lambda_t = E_t \beta \lambda_{t+1} [(1 - \delta) + (1 - \tau_{t+1}^k) u_{t+1}], \quad (22)$$

where equation (22) is obtained from the first-order condition for capital.

3.2 Firms

To produce output, I now assume that firms use labor h_t and capital k_t as inputs. The production technology is given by $F(k_t, h_t)$, which is homogeneous of degree one, and factors are paid their marginal products. As in section 2, it is assumed that a fraction of wage payments is subject to a CIA constraint given by equation (6).

The firm's objective is to maximize the expected present discounted value of profits. In order to do so, it uses $\beta^t \frac{\lambda_t}{\lambda_0}$ to discount profit flows to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \left\{ F(k_t, h_t) - w_t h_t - u_t k_t - m_t + \frac{m_{t-1}}{\pi_t} \right\},$$

subject to equation (6). Here $\pi_t = \frac{P_t}{P_{t-1}}$ denotes the gross consumer price inflation.

The first-order conditions for $\{h_t, k_t, m_t\}$ give the following conditions:

$$F_k(k_t, h_t) = u_t, \quad (23)$$

$$F_h(k_t, h_t) = (1 + \gamma(1 - R_t^{-1}))w_t. \quad (24)$$

The optimality condition (23) states the equality between the marginal product of capital and the rental rate of capital, and equation (24) has the same interpretation as the condition (9) we derived above.

3.3 The Government

As in the previous section, I assume that the government prints money, issues nominal one-period bonds, and levies distorting taxes to finance an exogenous stream of public consumption. The only difference here is that the fiscal authority, in addition to having access to distorting taxes on consumption and labor, is also allowed to tax capital income at rate τ_t^k . Accordingly, the government's sequential budget constraint becomes

$$\begin{aligned} M_t + B_t + P_t \tau_t^c c_t + P_t \tau_t^h w_t h_t + P_t \tau_t^k u_t k_t \\ = R_{t-1} B_{t-1} + M_{t-1} + P_t g_t. \end{aligned} \quad (25)$$

3.4 Competitive Equilibrium

Before defining the competitive equilibrium, note that the aggregate resource constraint due to the presence of physical capital takes the following form:

$$c_t + g_t + k_{t+1} - (1 - \delta) k_t = F(k_t, h_t). \quad (26)$$

A competitive equilibrium is now a set of plans $\{c_t, h_t, k_{t+1}, M_t, B_t, w_t, P_t, \lambda_t, R_t\}$ satisfying equations (3), (4), (5), (11), (12), (22), and (23), (24), (25), and (26), given policies $\{R_t, \tau_t^c, \tau_t^h, \tau_t^k\}$ and the initial conditions A_0 and k_0 .

As in the previous section, I first restrict the menu of taxes available to the fiscal authorities and study the optimality of the Friedman rule without a consumption tax (with taxes on capital

and labor income) and then discuss the case without labor taxes and with taxes on consumption. To this end, I begin by deriving the primal form of the competitive equilibrium and stating the Ramsey problem and then show that the Friedman rule is not optimal if fiscal instruments are restricted to taxes on labor income and capital or consumption and capital.

3.5 *Non-Optimality of the Friedman Rule with Distortionary Income and Capital Taxes*

In order to obtain the present-value implementability constraint, I do the same as before and iterate the government budget constraint forward and use the first-order conditions and also the fact that the production function exhibits constant returns to scale to eliminate prices, which leads to the same implementability condition obtained in the previous section in the model without capital:

$$E_0 \sum_{t=0}^{\infty} \beta^t [U_c(c_t, h_t) c_t + U_h(c_t, h_t) h_t] = \lambda_0 \left\{ B_0 + \frac{A_0}{P_0} \right\}, \quad (27)$$

given λ_0 , A_0 , P_0 , and $B_0 = [(1 - \delta) + (1 - \tau_0^k) u_0] k_0$.

The second implementability condition required for non-negativity of the nominal interest rate is also the same as condition (15). The Ramsey allocation problem must also satisfy the resource constraint (26).

PROPOSITION 3. *The Friedman rule in a model with capital and a cash-in-advance constraint on wage payments and distortionary taxes on income and capital is not optimal.*

Proof. The Ramsey problem consists in choosing a set of strictly positive sequences $\{c_t, h_t, k_{t+1}\}_{t=0}^{\infty}$ to maximize the representative household's utility function (1) subject to the feasibility constraint (26) and the implementability conditions (15) and (27), given $\lambda_0 \left\{ B_0 + \frac{A_0}{P_0} \right\}$.

This primal form of the equilibrium conditions is essentially the same as the one associated with the economy without capital except that the resource constraint is replaced by equation (26), which now

includes capital. Therefore, letting $\varphi > 0$ denote the Lagrange multiplier on the implementability constraint and ψ_t denote the Lagrange multiplier on the resource constraint, the first-order conditions of the Ramsey problem with respect to c_t are the same as before (equation (16)) and lead to a similar solution. The first-order conditions with respect to h_t and k_{t+1} imply that

$$\begin{aligned} \frac{\partial L}{\partial h_t} &= U_h(c_t, h_t) - \varphi U_{hh}(c_t, h_t) h_t + \varphi U_h(c_t, h_t) \\ &\quad + \varphi U_{ch}(c_t, h_t) c_t + \psi_t F_h(k_t, h_t) = 0 \end{aligned} \quad (28)$$

$$\frac{\partial L}{\partial k_{t+1}} = -\psi_t + \beta E_t \psi_{t+1} [F_k(k_{t+1}, h_{t+1}) + 1 - \delta] = 0. \quad (29)$$

If the Friedman rule holds, then $R_t = 1$. This requires that $U_c(c_t, h_t) = U_h(c_t, h_t) (1 - \tau_t^h)$. But, again, as the first-order conditions of the Ramsey problem make clear, we cannot conclude that relationship; that is, the Friedman rule is not also optimal in this context.

As I showed in the previous section in the case without capital, eliminating labor taxes and allowing for consumption tax doesn't change this conclusion. This remains also the case in the version of the model with capital. Moreover, with a sufficiently rich menu of taxes available to the fiscal authorities, τ_t^c , τ_t^h , and τ_t^k , the nominal interest rate, R_t , along with these taxes are not uniquely determined by the Ramsey allocation, so there are multiple fiscal policies that can implement that allocation. Some of these fiscal policies imply the optimality of the Friedman rule, and some do not.

Therefore, adding capital and imposing distortionary taxes on it does not change the result that the Friedman rule ceases to be optimal in a monetary model with a cash-in-advance constraint on wages, so long as the menu of taxes available to the government is restricted to taxes on income and capital or consumption and capital.

4. A Model with Money in the Production Function

Thus far, I have studied monetary economies in which demand for money by firms is originated in a cash-in-advance constraint on the

wage bill. In this section, I drop this assumption and replace it with—following Benhabib, Schmitt-Grohé, and Uribe (2001, 2002)—the assumption of money in the production function. For simplicity, I exclude labor from the model and assume that output is produced with money and capital. To finance its expenditure, the government is assumed to have access to distortionary taxes on consumption and capital. The main finding in this section is that the only solution to the Ramsey-optimal policy is to hold sufficient money to derive the marginal product of money to zero. That is, the Friedman rule emerges as the optimal policy even in the presence of distortionary consumption and capital taxes.

4.1 *The Economic Environment*

It is assumed that the representative household seeks to maximize the present value of utility

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t), \quad (30)$$

subject to its budget constraint

$$\begin{aligned} (1 + \tau_t^c) c_t + k_{t+1} + \frac{B_t}{P_t} = & [(1 - \delta) + (1 - \tau_t^k) u_t] k_t \\ & + \frac{R_{t-1} B_{t-1}}{P_t} + \Pi_t. \end{aligned} \quad (31)$$

The household chooses sequences $\{c_t, B_t, k_{t+1}\}_{t=0}^{\infty}$ so as to maximize (30) subject to the constraint (31), given that the no-Ponzi-game condition is assumed to be met. The optimality conditions associated with the household's problem are equations (5), (22), and

$$U_c(c_t) = \lambda_t (1 + \tau_t^c). \quad (32)$$

Output is assumed to be produced during period t by the stock of capital k_t and real money balances $m_t = \frac{M_t}{P_t}$ at the beginning of the period using the available technology $F(k_t, m_t)$, which is a homogeneous technology of degree one. Following Benhabib, Schmitt-Grohé, and Uribe (2001, 2002), I assume that the production function, $F(k_t, m_t)$, is positive, increasing, and concave in m_t . I also assume

that there is a point of satiation in real money balances $\bar{m}$ such that for $m \geq \bar{m}$, where $\bar{m}$ is a parameter, $F_m(k_t, m_t) = 0$.⁵

Firms seek to maximize the present value of their profits with respect to $\{k_t, m_t\}_{t=0}^{\infty}$, hence they maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \left\{ F(k_t, m_t) - u_t k_t - m_t + \frac{m_{t-1}}{\pi_t} \right\}.$$

The first-order conditions are equation (23) and

$$F_m(k_t, m_t) = 1 - R_t^{-1}, \quad (33)$$

and since in any equilibrium $R_t \geq 1$, therefore $F_m \geq 0$ in equilibrium must hold.

The government budget constraint is essentially the same as the one given by the constraint (25) except that now $\tau_t^h = 0$.

The following proposition provides the proof for the optimality of the Friedman rule in this model.

PROPOSITION 4. *The Friedman rule in a model with money in the production function and in the presence of distorting taxes on consumption and capital is optimal.*

Proof. The Ramsey problem is to maximize the expected lifetime utility (30) of the representative household by choosing $\{c_t, k_{t+1}, m_t\}$ subject to the resource constraint

$$c_t + g_t + k_{t+1} - (1 - \delta)k_t = F(k_t, m_t) \quad (34)$$

and the following single present-value implementability constraint:

$$E_0 \sum_{t=0}^{\infty} \beta^t U_c(c_t) c_t = \lambda_0 \left\{ B_0 + \frac{A_0}{p_0} \right\}, \quad (35)$$

⁵Benhabib, Schmitt-Grohé, and Uribe (2001, 2002) do not make such an assumption. I make it, however, following Chari, Christiano, and Kehoe (1996), who made such an assumption regarding the utility function in order to get around the technical problem of non-existence of a solution to the Ramsey allocation problem in the case in which the value of real money balances is infinite. In other words, this assumption ensures that the Friedman rule, a zero nominal interest rate, need not be associated with an infinite demand for money.

given $\lambda_0 = U_c(c_0)$, A_0 , p_0 , and B_0 . Let the Lagrange multiplier on the feasibility constraint (34) be denoted by ψ_t and the Lagrange multiplier on the implementability constraint (35) be denoted by ϕ . Then, the first-order conditions of the Ramsey problem are equation (29) and

$$U_c + \phi U_c + \phi c_t U_{cc} - \psi_t = 0, \quad (36)$$

and

$$\psi_t F_m(k_t, m_t) = 0. \quad (37)$$

The optimality condition for real money balances (37) is satisfied when either $\psi_t = 0$ or $F_m(k_t, m_t) = 0$. However, due to the insatiability of utility function, ψ_t is strictly positive. Therefore, the solution has to be $F_m(k_t, m_t) = 0$. In other words, despite the presence of distorting taxes on consumption and capital, it is optimal for the social planner to follow the Friedman rule and satiate the economy with money.

While, as I mentioned before, assuming a working capital constraint for firms is a very common assumption in the literature and recently has also received a big boost from the evidence that firms were hurt during the financial crisis, when they could not get access to credit to pay for working capital (see, e.g., Gilchrist et al. 2016), introducing money into the production function is not. However, it is interesting to see that the Friedman rule emerges as the optimal policy in this context and in the presence of distorting taxes without imposing any strong assumptions on preferences or the production function. This would also be the case if we include labor in the preferences and production function and allow for distorting taxes on labor income.

5. The Cash- and Credit-Goods Economy with a CIA Constraint on Wage Payments

Thus far, I have studied the optimality of the Friedman rule in monetary economies in which only firms have motivation to hold money. A more realistic monetary model would incorporate a money demand by households as well as firms. In sections 2 and 3 we saw that

the Friedman rule is not optimal when we rationalize a demand for money by firms by imposing that wage payments be subject to a cash-in-advance constraint. On the other hand, in the context of the cash- and credit-goods model of Lucas and Stokey (1983), Chari, Christiano, and Kehoe (1996) show that the Friedman rule in the presence of distortionary income taxes is optimal if utility is separable in leisure and homothetic in the cash and credit goods. Therefore, in this section, I study the Ramsey-optimal policy in a cash- and credit-goods model with distortionary income taxes and a working capital constraint on wages to see if the tradeoff between the calls for optimality of the Friedman rule (in a cash- and credit-goods model) and those deviating from the Friedman rule (in the monetary model with a CIA constraint on wages) is resolved and, if so, which model is favored. The model is essentially that of Chari, Christiano, and Kehoe (1996) with a CIA constraint on wages. The central result that emerges is that the optimality of the Friedman rule is unaltered by the introduction of a CIA constraint on wage payments.

5.1 The Model

Households are assumed to draw utility from cash goods c_{1t} and credit goods c_{2t} and disutility from labor effort h_t , according to the following function that satisfies the standard assumptions:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_{1t}, c_{2t}, h_t). \quad (38)$$

Expenditures on cash goods are subject to a cash-in-advance constraint of the form

$$\alpha c_{1t} \leq m_t^h, \quad (39)$$

where m_t^h stands for real money holdings by the household in period t and α is a constant that shows the fraction of consumption held in money.

The household's real budget constraint is given by

$$c_{1t} + c_{2t} + b_t + m_t^h = \frac{R_{t-1}B_{t-1} + M_{t-1}^h}{P_t} + (1 - \tau_t^h) w_t h_t + \Pi_t. \quad (40)$$

Assuming that households are subject to a borrowing limit that prevents them from engaging in Ponzi schemes, maximizing the utility function (38) subject to (39) and (40) gives (5) and the following first-order conditions:

$$U_{c_1}(c_{1t}, c_{2t}, h_t) = U_{c_2}(c_{1t}, c_{2t}, h_t) (1 + \alpha (1 - R_t^{-1})), \quad (41)$$

$$U_h(c_{1t}, c_{2t}, h_t) = \lambda_t (1 - \tau_t^h) w_t, \quad (42)$$

where λ_t is the Lagrange multiplier associated with the budget constraint (40). It is apparent from the first-order condition (41) that the nominal interest rate distorts the equality between the marginal utilities of cash and credit goods.

As in sections 2 and 3, I introduce a demand for money by firms by assuming that wage payments are subject to a cash-in-advance constraint of the form

$$\gamma w_t h_t \leq m_t^f, \quad (43)$$

where m_t^f denotes the demand for real money balances by firms in period t . Solving the firm's optimization problem gives exactly the same optimality condition as the one we derived in section 2, namely, equation (9). The government budget constraint is also of exactly the same form as equation (10) except that now $\tau_t^c = 0$.

The set of equilibria is characterized by the conditions (5), (9)–(10), (41)–(42), the resource constraint

$$c_{1t} + c_{2t} + g_t = h_t, \quad (44)$$

and the equation that governs total aggregate real balances

$$m_t = \alpha c_{1t} + \gamma w_t h_t, \quad (45)$$

together with the non-negativity constraint on the nominal interest rates, which can be written as

$$U_{c_1}(c_{1t}, c_{2t}, h_t) \geq U_{c_2}(c_{1t}, c_{2t}, h_t). \quad (46)$$

Again, apart from the resource constraint (44), we can condense the equilibrium conditions of the economy into the following single present-value implementability constraint:

$$\begin{aligned}
E_0 \sum_{t=0}^{\infty} \beta^t [U_{c_1}(c_{1t}, c_{2t}, h_t) c_{1t} + U_{c_2}(c_{1t}, c_{2t}, h_t) c_{2t} \\
+ U_h(c_{1t}, c_{2t}, h_t) h_t] = A_0 \frac{\lambda_0}{P_0}, \tag{47}
\end{aligned}$$

given $\lambda_0 = U_{c_1}(c_{10}, c_{20}, h_0)$, A_0 , and P_0 .

This primal form of the equilibrium conditions is essentially the same as the one associated with the Chari, Christiano, and Kehoe (1996) model, and introducing a CIA constraint on wages doesn't change it. Therefore, provided we maintain the homotheticity and weak separability assumptions about preferences, it can be shown, by virtually the same arguments as in Chari, Christiano, and Kehoe (1996), that the Friedman rule $R_t = 1$ holds in the presence of a working capital constraint on wage payments as well. The following proposition presents the proof of this statement.

PROPOSITION 5. *Suppose that preferences are homothetic in cash and credit goods and separable in labor effort. Then, under the Ramsey allocation, $R_t = 1$ for all $t > 0$.*

Proof. The Ramsey planner chooses processes $\{c_{1t}, c_{2t}, h_t\}$ in order to maximize lifetime discounted utility (38) subject to (44) and (47). Letting ψ_t and ϕ stand for the Lagrange multipliers associated with (44) and (47), the corresponding Ramsey first-order conditions for c_{1t} and c_{2t} are

$$(1 + \phi) U_{c_1} + \phi [U_{c_1 c_1} c_{1t} + U_{c_2 c_1} c_{2t} + U_{h c_1} h_t] = \psi_t \tag{48}$$

$$(1 + \phi) U_{c_2} + \phi [U_{c_1 c_2} c_{1t} + U_{c_2 c_2} c_{2t} + U_{h c_2} h_t] = \psi_t. \tag{49}$$

It can be shown that if the utility function is homothetic in c_{1t} and c_{2t} and separable in h_t , then the following condition holds:

$$\frac{U_{c_1 c_1} c_{1t} + U_{c_2 c_1} c_{2t}}{U_{c_1}} = \frac{U_{c_1 c_2} c_{1t} + U_{c_2 c_2} c_{2t}}{U_{c_2}}, \tag{50}$$

which, along with the Ramsey optimality conditions (48) and (49) and the consumer's first-order condition (41), shows that the Ramsey allocation gives the optimality of the Friedman rule.

Therefore, once the utility function is homothetic in c_{1t} and c_{2t} and separable in h_t , it is not optimal for the government to use inflation tax, even though it must rely on other distorting taxes. The reason is that under a positive nominal interest rate, an efficiency cost by distorting the consumer's optimal choice between credit good and cash good arises. While the presence of distortionary taxes and a cash-in-advance constraint on the wage bill of firms provides incentives for the Ramsey planner to deviate from the Friedman rule, the presence of a demand for money by households provides an incentive to set nominal interest rate at zero. Hence, we can conclude that if preferences are homothetic in cash and credit goods and separable in leisure, the tradeoff is resolved in favor of the Friedman rule. It is important, however, to note that dividing goods into cash and credit goods and then imposing homotheticity and separability conditions on preferences, which are very strong assumptions, are crucial and required for the optimality of the Friedman rule.

6. Conclusion

In this paper, I analyzed the optimality of the Friedman rule in different monetary economies without and with capital, where money enters into the models through a demand for money by firms motivated by either a working capital constraint on labor costs or money in the production function. Considering that a demand for money by firms is motivated by the fact that in industrialized countries, firms hold a substantial fraction of the cash balances. I first showed that the Friedman rule is not optimal, in the context of a model with and without capital, when firms are subject to a working capital constraint on wages and the government, in order to finance its expenditures, is restricted to impose distortionary taxes on either consumption or income. When the menu of taxes available to the fiscal authorities is sufficiently rich, I showed that the individual tax rates and the nominal interest rate are not uniquely determined by the Ramsey allocation, and therefore the Friedman rule may or may not be optimal. I then proved that the optimality of the Friedman rule is the only possible solution to the Ramsey allocation problem when output is produced with money held by the firms for production purposes. This is the case even with distorting taxes on consumption and capital. Furthermore, given the assumptions of homotheticity

and separability on preferences, I showed that the Friedman rule remains optimal in the context of a cash- and credit-goods model with an added cash constraint on wages.

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The Effects of Monetary and Exchange Rate Policy Shocks: Evidence from an Emerging Market Economy*

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Many central banks that have opted for monetary autonomy have also been reluctant to relinquish control over the value of their currencies. As a result, they have operated through both interest rate and foreign exchange interventions. Using daily data from the Central Bank of Turkey during the period of 2002–10, we study the effects of simultaneous policies by first purging the intended monetary decisions from responses to real-time macroeconomic variables and then determining their impact on economic activity. We find that the Central Bank of Turkey adjusted its policy rate mostly in response to inflation levels relative to both the yearly target and agents' expectations, and conducted purchases and sales of foreign currency in response to exchange rate behavior. These responses varied depending on whether interventions were pre-announced. In terms of effectiveness, we find that unannounced purchases of foreign currency had a significant effect in reducing exchange rate volatility but appeared to have no effect on exchange rate changes. Announced interventions, on the other hand, did have a significant impact on exchange rate changes and volatility. Finally, we find that changes in the policy rate affected inflation and output growth, with a lag delay of four and two quarters, respectively.

JEL Codes: E43, E52, E58, F31.

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1. Introduction

The *corner* (or *bipolar*) *hypothesis* and the *fix-or-float proposition* postulate that countries tend to move away from intermediate exchange rate regimes towards either hard pegs or fully flexible rates.¹ These concepts, which became conventional wisdom throughout the beginning of the 1990s, began to lose popularity after the East Asia crises of 1997–98 and the failure of Argentina's currency board in 2001. Since then, central banks have allegedly opted for monetary policy autonomy but have been reluctant to relinquish control over the value of their currencies. In fact, countries under an inflation-targeting regime have led concerted initiatives to affect the value of major currencies, some of which include the Smithsonian Agreement (1971), the Plaza and Louvre Accords (1985, 1987), the Chiang Mai Initiative (2000), and the Pittsburg Agreement (2009).

The Turkish case is no exception. Following the 2001 crisis, the Turkish economy underwent a structural transformation. The Central Bank of the Republic of Turkey (CBRT henceforth) was vested with independence and endowed with the primary objective of achieving and maintaining price stability. In 2002, the CBRT officially adopted an inflation-targeting regime and managed to bring high and chronic inflation down to single digits. Concurrently, in order to lower exchange rate volatility, the CBRT conducted foreign exchange interventions in one of two ways: (i) through *unannounced* interventions, often infrequent but large, and (ii) through *announced* interventions which consisted of predetermined dates and amounts, although with a discretionary (*optional*) amount of trading that took place during the day of the auction provided that monetary authorities decided to exceed the established amount.

In this paper we study the impact of simultaneous central bank policies in a unified framework. Namely, we analyze the effects of both interest rate and foreign exchange intervention on several macroeconomic variables that include inflation, output growth, and exchange rate behavior. Hence, our main objective is to evaluate the effectiveness of various types of central bank intervention. To this end, we extend the framework presented in Romer and Romer (2004) to allow for a bivariate policy model in which policy decisions are

¹See Eichengreen (1994) and Obstfeld and Rogoff (1995).

governed by dependent decision processes. Specifically, we model the undertakings of monetary authorities (tailored to the various foreign exchange mechanisms of the CBRT) using a parametric approach, and purge the intended monetary decisions from responses to high-frequency and real-time macroeconomic data. Hence, an advantage of our estimation is that it allows for non-linearities when extracting the unexpected component of policy.

A key feature of our identification strategy consists of matching the actions of monetary authorities with stated targets and observable covariates—in other words, to closely observe what monetary authorities observed, and to capture their direct undertakings, especially with a clear timing profile. To this end, we employ proprietary data from the CBRT, comprising all direct sales and purchases of foreign currency as well as changes in the policy rate. We note that our measure of the policy rate differs from any market-based rate (such as the interbank rate) in the sense that it more accurately captures the intended decisions of the CBRT.²

To date, empirical studies have yet to converge on the effects of foreign exchange intervention. For instance, studies by Menkhoff (2013) or Villamizar-Villegas and Perez-Reyna (2017) show that nearly half of the surveyed literature find non-significant or inconclusive results. And studies that do find a significant impact mostly conclude that exchange rate effects are small and short-lived (see, for example, Fatum and Hutchison 1999 and Neil and Fillion 1999).

Furthermore, studies that center on the Turkish economy are rather limited, and some even face the challenge of covering restricted periods in which interest rate cuts always preceded purchases of foreign currency, making it harder to disentangle policy-specific effects. Akinci et al. (2006), for example, study eleven direct intervention episodes during 2001–03 using a time-varying parameter model to analyze the effects on curbing exchange rate volatility. Guimaraes and Karacadag (2004) also study the effects on exchange rate levels and volatility during the same time frame, using a GARCH model. In turn, Kilinc and Tunc (2014) use a structural

²In several countries, including the United States, a researcher has to sometimes infer the intended policy rate with the use of narrative records (see Romer and Romer 2004). In other cases, studies simply use overnight market rates (see Kilinc and Tunc 2014).

VAR to study the effects of policy on the Turkish economy during 2006–13.

The study that most closely relates to ours is Herrera and Ozbay (2005), which studies central bank interventions using a dynamic censored regression model during 1993–2003. In contrast, our paper mainly focuses on the effects of simultaneous policies. Hence, the unified policy framework provided in this study makes our work more amenable for empirical analyses and enables us to control for various policy interactions. Additionally, we differ in our definition of censored interventions and we only focus on the time period in which the CBRT adopted an inflation-targeting regime.³

Our investigation confirms some of the previous findings from the literature, but also yields some new results. Similar to Villamizar-Villegas (2016), we find that the price puzzle (i.e., positive relationship between prices and the policy rate) disappears once monetary shocks are purged from systematic responses of policy. Also, in line with Romer and Romer (2004), we find that a monetary contraction lowers industrial output with a one-quarter lag delay. On the other hand, we find that unannounced purchases of foreign currency had a significant effect in reducing exchange rate volatility, but appeared to have no effect on exchange rate changes. This result is similar to those found in Dominguez (1993), Bonser-Neal and Tanner (1996), Baillie and Osterberg (1997), Chang and Taylor (1998), Fatum and Hutchison (2003), Domac and Mendoza (2004), and Humala and Rodriguez (2010). However, in contrast with this strand of the literature, we find that announced interventions can affect both exchange rate changes and volatility.⁴

To the best of our knowledge, only a handful of studies exist that directly address the issue of having multiple policy instruments, few of which estimate their dependence. In this sense, we believe that our investigation will shed some light on pressing monetary policy questions such as the following: Under what conditions do

³While Herrera and Ozbay (2005) treat all episodes of no intervention as censored, we consider a variety of different censoring scenarios, all of which are presented in section 2.4. As a result, we find that announced and unannounced interventions have different policy implications.

⁴A few authors, such as Neil and Fillion (1999), Kearns and Rigobon (2002), Fatum and Hutchison (2003), and Rincón and Toro (2010), also find a significant (albeit short-lived) effect on the exchange rate.

central banks intervene in the foreign exchange market? What are the effects of having multiple instruments? How long do these effects last? And, finally, are decisions about various policies conducted in an independent manner?

This paper proceeds as follows: Section 2 describes the data and emphasizes the various policy instruments undertaken by the CBRT. It also comments on the potential types of interventions that could have been censored by external factors. Section 3 presents the methodology, tailored to the different foreign exchange intervention mechanisms. Section 4 presents the results and section 5 concludes.

2. Data and Context

Our data cover the period of January 2002 through May 2010. This time frame was particularly chosen since, prior to 2002, a fixed exchange rate regime was established. Following the 2001 crisis, the Turkish economy underwent a structural transformation. The CBRT was vested with independence and endowed with the primary objective of achieving and maintaining price stability. In 2002, the CBRT officially adopted an inflation-targeting regime and managed to bring high and chronic inflation down to single digits.

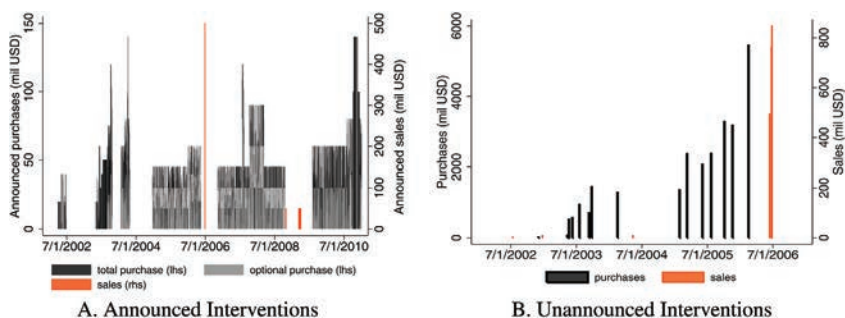
Following the quantitative easing (QE) program, and in order to address challenges posed by excess capital volatility, the CBRT adopted a set of additional monetary instruments in the second half of 2010, including a reserve option mechanism (ROM) and an interest rate corridor.⁵ Consequently, we feel that further assumptions are needed after May 2010 in order to disentangle the effects of the newly established tools on both the interest rate and the Turkish lira.

2.1 *Foreign Exchange Interventions*

In order to lower exchange rate volatility, the CBRT conducted foreign exchange interventions in one of two ways: (i) through unannounced interventions, exercised through direct sales and purchases of USD, and (ii) through announced interventions, consisting of

⁵See Kara (2013) for a review of unconventional monetary measures undertaken by the CBRT.

Figure 1. Different Types of Foreign Exchange Interventions Conducted by the CBRT



Notes: The left panel corresponds to sales and purchases of USD (in millions) through announced auctions along with optional purchases. The right panel corresponds to direct interventions. During the time of the study, it is clear that total purchases exceeded total sales.

predetermined dates and amounts, although with a discretionary (optional) amount of trading that took place during the day of the auction provided that monetary authorities decided to exceed the established amount.⁶ Announcements for this last type of interventions ranged from one day to two weeks prior to the currency auction. Also, the CBRT did not use a deterministic rule to decide over which date to intervene or the amount of currency to be traded.

The left panel of figure 1 depicts the total number of sales and purchases (in millions of USD) through announced auctions along with optional purchases of foreign currency (the CBRT never conducted optional sales). As shown, the CBRT purchased foreign currency throughout most of the sample, with optional purchases starting in September 2003, and occasional sales during 2006, 2008, and 2009. Alternatively, the right panel of figure 1 depicts the total number of sales and purchases (in millions of USD) through unannounced interventions. Under this type of trading, purchases and sales were infrequent but large, averaging \$1.7 and \$0.3 billion USD, respectively.

⁶There were limits on how much the CBRT could exceed the pre-established amount.

Similarly, table 1 shows the amount of foreign currency traded for every type of foreign exchange intervention. As seen, all purchases were larger than sales, by more than tenfold. As will be discussed in greater depth in the next section, this asymmetry reveals a systematic bias towards trying to depreciate domestic currency. As such, we address the *fear of floating* or rather, the *fear of appreciation*, by allowing some of these interventions to follow a censored Tobit type I model. Table 1 also shows that sales were largely concentrated in the year 2006. Purchases, on the other hand, were most abundant in 2003 and 2005.

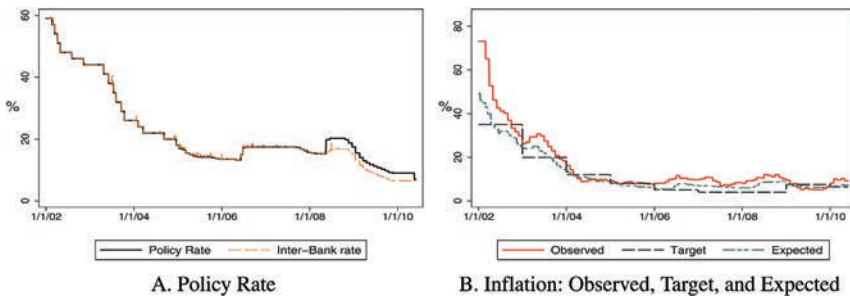
2.2 Policy Rate

Our measure of the policy rate corresponds to the CBRT's overnight borrowing rate between February 20, 2002 and May 16, 2008 (due to the abundant liquidity in the Turkish market); to the overnight lending rate between May 17, 2008 and May 20, 2010 (due to the liquidity shortage); and to the one-week repo lending rate after May 21, 2010. As such, our investigation differs from studies that use market-based rates such as the interbank rate. We argue that the latter can be more likely influenced by monetary factors driven by liquidity demand, as they comprise equilibrium conditions which reflect transactions within the financial system, including those between commercial banks and other non-banking entities. However, we conduct robustness exercises (reported in figure 10 in appendix 3) in order to assess the differences obtained if we had instead used the interbank rate.

Figure 2 depicts our measure of the policy rate and the interbank rate (left panel), as well as the observed, targeted, and expected yearly inflation (right panel). The figure shows that at the onset of 2002, inflation (or hyperinflation) levels reached 73.2 percent, while the target for inflation was set at 35 percent and the policy rate (depicted in the left panel) was set at 59 percent. With a sharp disinflation in 2001, the policy rate began to steadily decline until mid-2006. Starting in mid-2006, interest rates slightly rebounded but started falling again in 2008.

The positive relationship between inflation and interest rates can be misconstrued as evidence of the price puzzle. Nonetheless, a more reasonable explanation was that the CBRT kept interest rates high

**Figure 2. Policy Rate and Yearly Inflation
(observed, target, and expected)**



Notes: The left panel corresponds to the CBRT policy rate. The right panel corresponds to the observed inflation, to the surveyed one-year-ahead expected inflation forecast, and to the yearly target.

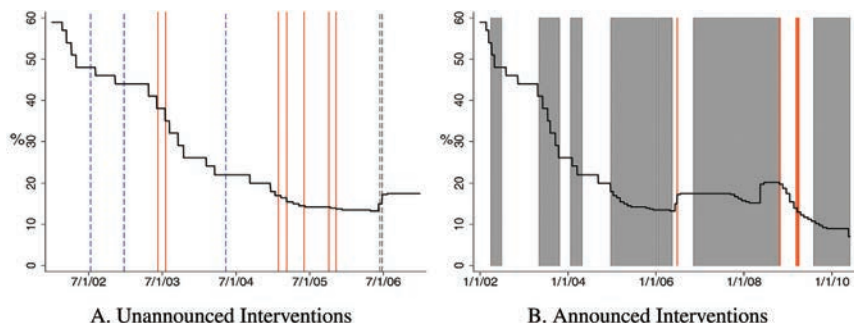
to bring inflation down to single digits, and only conducted expansionary monetary policy once inflation decreased. In section 4.4 we show that the price puzzle is eliminated by purging the policy rate from systematic responses of policy.

2.3 Simultaneous Policies: *Leaning with or against the Wind?*

Figure 3 depicts episodes in which the CBRT conducted announced and unannounced purchases and sales of foreign currency, along with changes in the policy rate. In the left panel, the solid (dashed) lines denote unannounced purchases (sales) of foreign currency. Hence, it shows that purchases were used in tandem with the policy rate, as they were conducted during episodes of interest rate cuts. However, as shown by the blue dashed lines,⁷ there were some episodes in 2002 and 2004 in which the CBRT conducted *leaning-against-the-wind* policies (i.e., interest rate cuts along with sales of foreign currency).

Similarly, the right panel of figure 3 shows that in 2008 and 2009, announced sales (orange lines) coincided with interest rate

⁷Colors appear in the online version, available at <http://www.ijcb.org>.

Figure 3. Simultaneous Monetary Policies

Notes: The left panel corresponds to unannounced interventions, where solid (dashed) lines denote purchases (sales) of foreign currency. Some purchases were not included given that they did not occur within one week of a policy rate change. The right panel corresponds to announced interventions, where shaded regions (solid lines) denote purchases (sales) of foreign currency.

cuts, exerting potentially opposing forces on the exchange rate.⁸ Lastly, given the high number of announced purchases throughout the sample, they coincided with both interest rate hikes (*leaning against the wind*) and interest rate cuts (*leaning with the wind*).

2.4 Censored Interventions

Earlier we highlighted the asymmetry between purchases and sales of foreign currency conducted by the CBRT. That is, while purchases totaled 74.5 billion USD, sales totaled only 4.12 billion USD (see table 1). When modeling the various policy functions for foreign exchange intervention, the general absence of USD sales can take on two different interpretations: (i) either economic conditions were such that it was optimal for the CBRT to conduct only purchases of USD, or (ii) economic conditions were such that it was optimal for the CBRT to conduct sales of USD, but it did not carry them out given some external factor or constraint. The latter describes a

⁸Leaning-against-the-wind policies of both announced and unannounced foreign exchange interventions generally took place during heightened global financial market volatility, as can be seen in figure 9 of appendix 2.

**Table 2. Foreign Exchange Interventions
Considered as Censored**

Type	Censored	Not Censored
Unannounced Total (Purchases – Sales)		X
Unannounced Purchases	X	
Unannounced Sales	X	
Optional Purchases	X	
Announced Purchases		X
Announced Sales		X
Changes in Policy Rate		X

censored process that, if estimated with a linear model, would yield inconsistent estimates.⁹

As such, table 2 describes the different specifications considered in this study when modeling policy. In essence, announced interventions and changes in the policy rate were not considered as being censored, while optional purchases were considered as censored given the complete lack of optional sales. Finally, unannounced interventions were considered as both censored (when taking sales and purchases individually) and uncensored (when taking the total). The main reasons for allowing unannounced interventions to have both specifications were to establish a benchmark comparison with other studies that also assume censored policy processes,¹⁰ as well as to analyze the importance of the conditional probability of observing a positive intervention, by comparing both types of estimations.

3. Methodology

3.1 Policy Effects in a Potential Outcomes Framework

The main challenge of estimating the effects of policy is that monetary decisions are rarely isolated from economic developments. In a potential outcomes framework, this corresponds to not being able

⁹See Cohen (1949), Rosenbaum (1961), or Barr and Sherrill (1999).
¹⁰See, for example, Herrera and Ozbay (2005) and Villamizar-Villegas (2016).

to properly account for the systematic differences between treatment and control groups (i.e., intervention versus non-intervention episodes). For instance, assume that we are interested in the causal effect of purchasing “ s ” units of foreign currency. A counterfactual of interest can be stated as the effects of purchasing “ s ” given that the central bank actually purchased “ $s - j$.”¹¹ However, conditions could have significantly differed for when the CBRT purchased “ s ” or “ $s - j$ ” (which most likely explains the difference in intervention values).

To see this point more formally, let Y_t be a vector of outcome variables, D_t a vector of policy instruments, and X_t a matrix of covariates needed to characterize the various policy functions. Histories of policy, outcomes, and exogenous variables are characterized as

$$\begin{bmatrix} \bar{D}_t \\ \bar{X}_t \\ \bar{Y}_t \end{bmatrix} = \begin{bmatrix} D_t & D_{t-1} & \cdots & D_{t-k} \\ X_t & X_{t-1} & \cdots & X_{t-k} \\ Y_t & Y_{t-1} & \cdots & Y_{t-k} \end{bmatrix}, \quad (1)$$

and the “relevant” statistic that policymakers use to determine policy at time “ t ” can be described by $z_t = \Phi_t(\bar{Y}_t, \bar{X}_t, \bar{D}_{t-1})$, for a given mapping Φ_t .

In principle, differences in outcome variables, whenever the CBRT purchased “ s ” units of foreign currency compared with when it purchased “ $s - j$,” can be formulated as follows:

$$E[Y_{t,s} \mid D_t = s] - E[Y_{t,s-j} \mid D_t = s - j] = \quad (2)$$

$$\begin{aligned} & E[Y_{t,s} - Y_{t,s-j} \mid D_t = s] + E[Y_{t,s-j} \mid D_t = s] \\ & - E[Y_{t,s-j} \mid D_t = s - j], \end{aligned} \quad (3)$$

where $Y_{t,s}$ corresponds to the vector of potential outcomes had the bank purchased “ s ” units of foreign currency, regardless of the actual amount purchased. Alternatively, observed purchases are dictated by the realization of D_t . The step between equations (2) and (3) simply corresponds to the addition and subtraction of the term $E[Y_{t,s-j} \mid D_t = s]$, that is, the conditional mean of Y_t had the CBRT purchased “ $s - j$ ” units of foreign currency when it in fact purchased “ s .”

¹¹Note that “ j ” can be set equal to “ s ” for the case of no interventions.

Equation (3) is hence comprised of three terms. The first term is our variable of interest and captures the average treatment effect (ATE) of purchasing “ j ” additional units of foreign currency (from “ $s - j$ ” to “ s ”), given a purchase of “ s .” The second and third terms constitute the resulting bias that arises due to the non-randomization of treatment assignment.¹²

Fortunately, the conditional independence assumption (CIA henceforth) allows us to eliminate this bias. Namely, the CIA states that conditional on the relevant history, policy decisions are independent of potential outcomes, or as good as randomly assigned. This assumption, sometimes known as the selection-on-observables assumption, establishes the foundation based on which “regressions can also be used to approximate experiments in the absence of random assignment.”¹³ Formally, the CIA can be stated as equation (4):

$$Y_{t,s}(d_t) \perp D_t \mid z_t \quad \forall d \in D, \forall s. \quad (4)$$

Consequently, the bias that corresponds to the second and third terms of equation (3) cancels out as shown:

$$\begin{aligned} BIAS &= E[Y_{t,s-j} \mid z_t, D_t = s] - E[Y_{t,s-j} \mid z_t, D_t = s - j] \\ &= E[Y_{t,s-j} \mid z_t, D_t = s] - E[Y_{t,s-j} \mid z_t, D_t = s] \\ &= 0. \end{aligned} \quad (5)$$

Equation (5) follows from the fact that policy instruments are independent of potential outcomes. As such, it is essential to extract the random component of policy from anything that may systematically react to informative variables. In the empirical application, it justifies the two-step procedure of first identifying exogenous monetary shocks and then estimating their effects on the economy. Accordingly, the first step of our methodology consisted of modeling the various policy rules in order to remove systematic responses to informative variables.

¹²For example, when evaluating the effects of policy on inflation, it is reasonable to argue that the bias in equation (3) will most likely be positive, $E[Y_{t,s-j} \mid D_t = s] > E[Y_{t,s-j} \mid D_t = s - j]$, falsely attributing a greater effect on policy.

¹³Angrist and Pischke (2009, p. 18).

3.2 Computation of Monetary Shocks

3.2.1 Uncensored Policies

When computing monetary shocks, there is no reason to believe that policy decisions were independent. After all, the CBRT conducted monetary policy through both foreign exchange interventions (FXI henceforth) and interest rate interventions (IRI henceforth), and it is entirely plausible that decisions about one instrument altered the probability distribution of the other.¹⁴ We thus proceed by parameterizing this dependence as follows:

$$\begin{aligned} FXI_t^* &= x_{1t}'\beta_1 + \epsilon_{1t} \\ IRI_t &= x_{2t}'\beta_2 + \epsilon_{2t} \\ \begin{pmatrix} \epsilon_{1t} \\ \epsilon_{2t} \end{pmatrix} &\sim N(0, \Sigma), \end{aligned} \quad (6)$$

where the residuals of both policy functions (i.e., policy shocks) are assumed to be jointly normal with zero mean and variance-covariance matrix $\Sigma = \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix}$.

The construction of a maximum-likelihood function for the bivariate process described in equation (6) is hence warranted in order to obtain estimates of all individual regressors as well as the estimated covariance between policy shocks. The corresponding bivariate normal likelihood is presented as

$$L_n(\theta) = \prod_{t=1}^T \frac{1}{(2\pi)^{1/2} |\Sigma|^{1/2}} e^{-\frac{1}{2}(D_t - \mu)' \Sigma^{-1} (D_t - \mu)}, \quad (7)$$

where $D_t = \begin{bmatrix} FXI_t \\ IRI_t \end{bmatrix}$ and $\mu = E_t \begin{bmatrix} x_{1t}'\beta_1 \\ x_{2t}'\beta_2 \end{bmatrix}$. If the estimation of the maximum likelihood yields a significant covariance between policy residuals (σ_{12}), shocks can then be computed in vector form in order to account for the conditional dependence of policy. Otherwise, they can be computed by estimating linear fitted residuals of independent processes characterized by equation (6).

¹⁴In fact, the left panel of figure 3 suggests that both interest rate and foreign exchange interventions were sometimes orchestrated.

3.2.2 Censored Policies

Table 2 denotes which types of FXI were considered as censored and thus modeled with a Tobit type I model. We proceed to parameterize the maximum-likelihood function for the bivariate policy process in which FXI exhibit some degree of censoring.

Formally, let $A \equiv \left(\sigma_1^2 - \frac{\sigma_{12}^2}{\sigma_2^2}\right)$ and $b \equiv (x'_{1t}\beta_1 + \frac{\sigma_{12}}{\sigma_2^2}(IRI_t - x'_{2t}\beta_2))$. It follows that

$$\begin{aligned}
 L_n(\theta) &= \prod_{FXI_t^* \leq 0} f(FXI_t, IRI_t \mid x_{1t}, x_{2t}) \\
 &\times \prod_{FXI_t^* > 0} f(FXI_t, IRI_t \mid x_{1t}, x_{2t}) \\
 &= \prod_{FXI_t^* \leq 0} \left(1 - \Phi\left(\frac{b}{A^{1/2}}\right)\right) \frac{1}{\sigma_2} \phi\left(\frac{IRI_t - x'_{2t}\beta_2}{\sigma_2}\right) \\
 &\times \prod_{FXI_t^* > 0} \frac{1}{A^{1/2}} \phi\left(\frac{FXI_t^* - b}{A^{1/2}}\right) \frac{1}{\sigma_2} \phi\left(\frac{IRI_t - x'_{2t}\beta_2}{\sigma_2}\right), \quad (8)
 \end{aligned}$$

where $\phi(\cdot)$ and $\Phi(\cdot)$ correspond to the probability distribution function and the cumulative distribution function of a standard normal distribution, respectively. Similar to the case of uncensored policies, if the estimation of the maximum likelihood yields a significant covariance between policy residuals (σ_{12}), they can be computed in vector form as presented in Villamizar-Villegas (2016). However, if the covariance is not significant, policy shocks can be obtained by subtracting the conditional mean of policy from its observed value, as follows:

$$\begin{aligned}
 \epsilon_{1t} &= FXI_t - E[FXI_t \mid x_{1t}] \\
 &= FXI_t - \Phi\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right) \left[x'_{1t}\beta_1 + \sigma_1\lambda\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right)\right] \quad (9)
 \end{aligned}$$

$$\begin{aligned}
 \epsilon_{2t} &= IRI_t - E[IRI_t \mid x_{2t}] \\
 &= IRI_t - x'_{2t}\beta_2, \quad (10)
 \end{aligned}$$

where the term $\lambda(\cdot) = \phi(\cdot)/\Phi(\cdot)$ corresponds to the inverse Mills ratio. The term $\Phi\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right)$ of equation (9) represents the probability of observing a positive intervention (i.e., $Pr(FXI_t^* > 0 \mid x_{1t})$), whereas the last term in brackets is the expected value of the latent variable FXI_t^* .¹⁵

3.3 Impulse Response Functions

The second step of the methodology consisted of estimating the effects of the estimated residuals, ϵ_{1t} and ϵ_{2t} , on the different outcome variables in Y_t . To this end, we estimated impulse response functions (IRFs) for variables with a monthly frequency according to Jordà's (2005) methodology of local projections:

$$Y_{it+s} = \eta_0^s + \eta_1^s \epsilon_{1t} + \eta_2^s \epsilon_{2t} + \vartheta_{it+s} \quad \text{for } s = 0, 1, \dots, h. \quad (11)$$

In this case, the correlation between policy lags disappears since shocks are summed up into monthly observations. Conversely, we estimated IRFs for variables with a daily frequency according to the methodology of Romer and Romer (2004):

$$Y_{it} = \gamma_0 + \sum_{j=0}^h \gamma_j \epsilon_{1t-j} + \sum_{k=0}^h \gamma_k \epsilon_{2t-k} + \varsigma_{it}. \quad (12)$$

Coefficients and standard errors (bootstrapped) were summed up every period in order to obtain the cumulative effect across time.¹⁶

4. Estimation and Results

4.1 Parametric Dependence of Monetary Shocks

Estimation results for the maximum-likelihood function of equations (7) and (8) are reported in table 3. Values correspond to the

¹⁵Residuals ϵ_{1t} and ϵ_{2t} correspond to the policy shocks for FXI_t and IRI_t , respectively.

¹⁶The number of lags varied depending on the frequency of the outcome variable ($h = 12$ if monthly, $h = 40$ if daily). IRFs were smoothened using a moving average of $\pm$ two lags, for readability purposes only.

Table 3. Covariances of Bivariate Process

Bivariate Model	Uncensored	Censored
FX Unannounced Total – Policy Rate	–0.05 (0.034)	
FX Announced Purchases – Policy Rate	–0.02 (0.034)	–0.06 (0.041)
FX Announced Sales – Policy Rate	0.08** (0.034)	0.65*** (0.208)
FX Unannounced Purchases – Policy Rate		0.40 (0.289)
FX Unannounced Sales – Policy Rate		0.10 (0.205)
FX Optional Purchases – Policy Rate		–0.08 (0.064)

Notes: All models consisted of 2,190 observations. Log-likelihoods for each model correspond to 1492.2, 8498.65, and 8592.0 for the uncensored specification, respectively, and to 875.1, 889.4, 5234.1, and 3185.1 for the censored specification, respectively. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent level, respectively. Standard errors are reported in parentheses.

covariance between v_t and ϵ_{2t} . As can be observed, none of the covariances are statistically significant except for the covariance between announced sales and the policy rate. For computational purposes, policy shocks were estimated according to equation (9) (for censored observations of announced purchases, unannounced purchases and sales, and optional purchases); equation (10) (for uncensored observations of policy rate changes); fitted residuals equivalent to when $\Phi\left(\frac{x'_{1t}\beta_1}{\sigma_1}\right) = 1$ in equation (10) (for uncensored observations of unannounced totals, and announced purchases and sales); and equation (7) (for announced sales) when computing shocks in vector form.

Interestingly, most of these covariances turn significant when excluding inflation values relative to the yearly target from X_t (all except unannounced trades whose covariance is not significant across the different specifications of X_t). These findings indicate that, under the assumptions of the model, the CBRT’s decisions of one instrument (conditional on X_t) did not alter the probability distribution

of the other. However, this result does not mean that different policies did not react to the same target. In fact, many covariates that were included in x_{1t} were also included in x_{2t} .¹⁷ Independence, in this case, is conditional on the set of control variables.

4.2 Policy Functions

Small open economies, such as Turkey, are known to be vulnerable to global financial conditions. As such, it is important to control for variables that affect both the financial and macroeconomic cycle. As Rey (2015, p. 21) states, “Fluctuating exchange rates cannot insulate economies from the global financial cycle, when capital is mobile. The ‘trilemma’ morphs into a ‘dilemma’—independent monetary policies are possible if and only if the capital account is managed, directly or indirectly, regardless of the exchange-rate regime.” We thus proceed by including variables such as the VIX index and the SPG Commodity Channel Index (SPGCCCI) in the estimations that follow. All other variables included in our estimations are described in appendix 1, and their stationarity properties are reported in table 10 of appendix 4.¹⁸

Tables 4–7 show results for all the various types of foreign exchange policy functions. Table 4 shows that unannounced total interventions mostly reacted to the exchange rate behavior (measured in Turkish lira per U.S. dollar (TRY/USD)). That is, the CBRT tried to depreciate domestic currency by purchasing USD whenever the exchange rate appreciated (relative to the daily, weekly, and monthly exchange rate) and whenever exchange rate volatility increased. In specifications 3 and 4, interventions positively responded to lagged announced purchases of USD (exhibiting some momentum effect) as well as to changes in the policy rate (specification 3), indicating a leaning-against-the-wind policy.¹⁹

¹⁷An example is lagged interest rate interventions (ΔIRI_{t-1}), which were included in all specifications.

¹⁸We are grateful to an anonymous referee for suggesting these variables as proxies of global financial conditions. We also conducted additional exercises (not reported) using changes in the oil price (BRENT) instead of the SPGCCCI index, yielding similar results.

¹⁹The CBRT purchased foreign currency while simultaneously conducting contractionary monetary policy.

Table 4. OLS Estimation: $FXI_t^{total} = x'_{1t}\beta_1 + v_t$

FX Unannounced Total (Uncensored)	(1)	(2)	(3)	(4)
FXI_{t-1}^{total}	0.00 (0.010)	0.00 (0.010)	0.00 (0.009)	0.00 (0.009)
Inflation(π_{t-1}) – Target(π_{t-1}^*)	–8.01 (9.582)	–8.53 (9.670)	–11.10 (10.131)	–11.09 (10.064)
Industrial Production ΔInd_{t-1}	0.68* (0.368)	0.73* (0.376)	0.54 (0.383)	0.31 (0.421)
Daily Depreciation Δe_{t-1}	–4.09* (2.102)	–4.66** (2.202)	–4.68*** (2.195)	–6.07** (2.824)
Weekly Depreciation Δe_{t-5}	–2.07* (1.126)	–2.37** (1.192)	–2.70** (1.225)	–2.95** (1.264)
Monthly Depreciation Δe_{t-20}	–0.85* (0.491)	–1.08*** (0.668)	–0.90** (0.466)	–0.55 (0.546)
Exchange Rate Vol_{t-1}		1.41** (0.669)	1.60** (0.694)	1.69** (0.669)
Announced Purchases $_{t-1}$			0.51*** (0.185)	0.51*** (0.186)
Inflation Surprises ($\pi_{t-1} - \pi_{t-1}^e$)			0.00 (0.326)	0.05 (0.300)
Policy Rate ΔIRI_{t-1}			3.70* (2.207)	3.18 (2.108)
VIX $_{t-1}$				–0.42 (0.396)
Commodity Index $\Delta SPGCCl_{t-1}$				–0.87* (0.523)
Notes: Specifications $x_{1t}(1-4)$ correspond to the different combinations of covariates. FX intervention is measured in millions of USD. All specifications consisted of 2,190 observations. $R^2 = 0.005, 0.005, 0.007$, and 0.007 for OLS specifications 1–4. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent level, respectively. Standard errors are reported in parentheses. Constant and year dummies not reported.				

Additionally, specifications 1 and 2 show a positive effect of industrial output growth on USD purchases.²⁰ Finally, specification 4 shows that the CBRT purchased USD whenever commodity prices

²⁰The effect of industrial output is not significant in specifications 3 and 4, possibly due to the high correlation between lagged output growth and the policy rate.

Table 5. Tobit Estimation: $FXI_t = \max[0, x'_{1t}\beta_1 + v_t]$

Unannounced FXI (Censored)	Purchases	Sales
Inflation(π_{t-1}) – Target(π_{t-1}^*)	–1.87 (1.233)	0.27 (0.359)
Industrial Production ΔInd_{t-1}	0.13 (0.095)	0.04 (0.036)
Weekly Depreciation Δe_{t-5}	–3.23* (1.654)	0.69* (0.417)
Monthly Depreciation Δe_{t-20}	–0.80*** (0.303)	0.08* (0.040)
Exchange Rate Vol_{t-1}	–0.39 (0.761)	–0.22 (0.143)
Policy Rate ΔIRI_{t-1}	0.50 (1.614)	–0.08 (0.499)
VIX $_{t-1}$	–0.36** (0.174)	0.00 (0.018)
Commodity Index $\Delta SPGCCI_{t-1}$	–0.10 (0.099)	0.00 (0.032)
Notes: Specifications $x_{1t}(1-2)$ correspond to the different combinations of covariates. FX intervention is measured in millions of USD. All specifications consisted of 2,190 observations. Pseudo $R^2 = 0.12$ and 0.23 for Tobit specifications 1–2. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent level, respectively. Standard errors are reported in parentheses. Constant and year dummies not reported.		

(*SPGCCI*) decreased. Similarly, table 5 shows results for censored unannounced sales and purchases, when considered individually. Results are similar to those of table 4: purchases (sales) followed appreciating (depreciating) exchange rate episodes. One difference, nonetheless, is the significant effect of the VIX index on unannounced purchases.²¹

Table 6 presents the estimation results for optional purchases (recall that this type of FXI was considered as censored, given the complete lack of optional sales). Surprisingly, results show that many

²¹Tables 4–7 show that responses of the CBRT to global financial conditions (proxied by the VIX index) were addressed through either unannounced and optional purchases or through announced sales.

Table 6. Tobit Estimation: $FXI_t^{optional} = \max[0, x'_{1t}\beta_1 + v_t]$

FX Optional Purchases (Censored)	(1)	(2)	(3)	(4)
$FXI_{t-1}^{optional}$	0.93*** (0.048)	0.93*** (0.048)	0.65*** (0.048)	0.62*** (0.048)
Inflation(π_{t-1}) – Target(π_{t-1}^*)	-0.52*** (0.143)	-0.51*** (0.143)	-0.43*** (0.144)	0.67*** (0.164)
Industrial Production ΔInd_{t-1}	0.53*** (0.082)	0.51*** (0.083)	0.28*** (0.083)	0.03 (0.097)
Monthly Depreciation Δe_{t-20}	-0.60*** (0.190)	-0.48** (0.203)	-0.44** (0.202)	-0.02 (0.213)
Exchange Rate Vol_{t-1}		-0.64 (0.399)	-0.53 (0.391)	-0.36 (0.399)
Announced Purchases $_{t-1}$			0.70*** (0.054)	0.72*** (0.055)
Unannounced Purchases $_{t-1}$			0.00 (0.003)	0.00 (0.003)
Policy Rate ΔIRI_{t-1}			3.76 (3.000)	2.92 (2.918)
VIX $_{t-1}$				-0.72*** (0.111)
Commodity Index $\Delta SPGCCI_{t-1}$				0.03 (0.095)
Notes: Specifications $x_{1t}(1-4)$ correspond to the different combinations of covariates. FX intervention is measured in millions of USD. All specifications consisted of 2,190 observations. Pseudo $R^2 = 0.06, 0.06, 0.07,$ and 0.11 for Tobit specifications 1–4. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent level, respectively. Standard errors are reported in parentheses. Constant and year dummies not reported.				

variables affected the decision to optionally intervene in the foreign exchange market, as if expected by market participants.²² In this case, the CBRT tried to depreciate domestic currency by purchasing USD whenever inflation was low (relative to the yearly target), whenever industrial output increased, and whenever the monthly

²²This can be explained by the numerous times that the CBRT conducted optional purchases. In fact, after September 2003, the CBRT almost always exceeded the pre-established amount.

Table 7. OLS Estimation: $FXI_t = x'_{1t}\beta_1 + v_t$

Announced FXI (Censored)	Purchases	Sales
FXI_{t-1}	0.82*** (0.021)	0.16 (0.139)
$Inflation(\pi_{t-1}) - Target(\pi_{t-1}^*)$	1.34*** (0.354)	0.39** (0.167)
Industrial Production ΔInd_{t-1}	0.06*** (0.017)	-0.08*** (0.019)
Monthly Depreciation Δe_{t-20}	-0.11** (0.048)	0.03 (0.059)
Exchange Rate Vol_{t-1}	-0.05 (0.065)	-0.05 (0.058)
Unannounced Purchases $_{t-1}$	0.002* (0.001)	0.00 (0.001)
Unannounced Sales $_{t-1}$	-0.002 (0.002)	0.47*** (0.132)
Inflation Surprises $(\pi_{t-1} - \pi_{t-1}^e)$	-0.11*** (0.036)	-0.04*** (0.012)
Policy Rate ΔIRI_{t-1}	-1.12** (0.571)	0.06 (0.998)
VIX $_{t-1}$	-0.01 (0.014)	0.04** (0.016)
Commodity Index $\Delta SPGCCI_{t-1}$	0.02 (0.016)	0.02 (0.023)
Notes: Specifications $x_{1t}(1-2)$ correspond to the different combinations of covariates. FX intervention is measured in millions of USD. All specifications consisted of 2,190 observations. $R^2 = 0.74$ and 0.79 for OLS specifications 1-2. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent level, respectively. Standard errors are reported in parentheses. Constant and year dummies not reported.		

exchange rate appreciated.²³ Specifications 3 and 4 also show that interventions positively responded to past purchases of announced interventions. Finally, specification 4 shows a significant and negative impact of the VIX index.

²³The CBRT could have reacted to inflation levels, as some authors argue that even sterilized interventions can have an effect on prices via liquidity premiums (see Canzoneri and Cumby 2013).

Table 7 shows results for announced sales and purchases. While purchases were conducted after positive changes in industrial output growth, sales followed negative changes in output. Also, purchases were conducted whenever the monthly exchange rate appreciated, but sales seemed not to respond to exchange rate changes. We believe, however, that this is due to the scant number of sales within our sample. Additionally, sales and purchases reacted to inflation changes (relative to both the target and expected inflation).

In sum, these results are similar to those found in Kamil (2008) and Echavarria et al. (2013) in that central banks are inclined to purchase (sell) foreign currency whenever the exchange rate appreciates (depreciates). However, a novel feature in our investigation is that responses mostly varied depending on whether interventions were pre-announced.

Similar to Romer and Romer (2004), the IRI_t policy function of equation (6) was estimated using OLS around meeting date “ m ” of the open market committee of the CBRT. This setting (like in Romer and Romer 2004) assumes that unemployment acts through the measure of GDP gap (i.e., Okun’s Law). Results are reported in table 8. Coefficients of the lagged policy rate ΔIRI_{t-1} are small and for the most part not statistically significant. Estimates also show that the main explanatory variable was inflation relative to the yearly target (i.e., the CBRT conducted contractionary policy in order to lower inflation). Other variables that prompted policy adjustments were lagged values of announced purchases and unannounced sales, weekly and monthly exchange rate changes, and the VIX index (i.e., the CBRT conducted monetary easing when market turmoil increased). We note that the negative impact of inflation surprises on policy adjustments is conditional to the inclusion of inflation changes with respect to the target rate. In many specifications, the effect of inflation surprises is reversed when excluding all other measures of inflation. The decision to include both measures of inflation was justified by their medium-to-low correlation of 0.32. In all specifications, the CBRT did not seem to respond to changes in the U.S. federal funds rate nor industrial output.

4.3 Policy Shocks

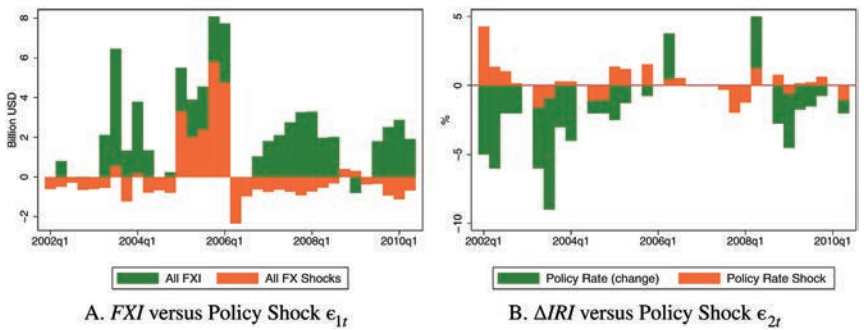
Figure 4 depicts the resulting monetary shocks ($\epsilon_{1t}, \epsilon_{2t}$) compared with the observed policy instruments (FXI_t, IRI_t). To improve

Table 8. OLS Estimation: $\Delta IRI_m = x'_{2t}\beta_2 + \epsilon_{2t}$

Policy Rate Changes (Uncensored)	(1)	(2)	(3)	(4)
ΔIRI_{m-1}	0.35* (0.202)	0.24 (0.171)	0.20 (0.176)	0.12 (0.152)
Inflation(π_{t-1}) – Target(π^*_{t-1})	0.19* (0.099)	0.22** (0.099)	0.23** (0.103)	0.28*** (0.066)
Weekly Depreciation Δe_{t-5}	–0.13* (0.075)	–0.19*** (0.064)	–0.19*** (0.061)	–0.12 (0.078)
Monthly Depreciation Δe_{t-20}	0.06* (0.028)	0.06* (0.033)	0.06** (0.025)	0.07* (0.031)
Industrial Production ΔInd_{t-1}	0.01 (0.015)	0.00 (0.014)	0.01 (0.017)	0.05 (0.034)
Inflation Surprises ($\pi_{t-1} - \pi^e_{t-1}$)	–0.15** (0.063)	–0.18*** (0.058)	–0.19*** (0.059)	–0.14 (0.072)
U.S. Federal Funds Rate Δi^*_{t-1}	–1.99 (3.244)	–0.71 (3.136)	–0.51 (2.831)	–1.63 (2.865)
Unannounced Sales $_{t-1}$		0.003*** (0.001)	0.003*** (0.001)	0.002 (0.001)
Announced Purchases $_{t-1}$			–0.01 (0.006)	–0.02*** (0.008)
VIX $_{t-1}$				–0.05** (0.021)
Commodity Index $\Delta SPGCCI_{t-1}$				0.01 (0.021)
Notes: Specifications $x_{1t}(1-4)$ correspond to the different combinations of covariates. All models consisted of fifty-two observations given that estimations were conducted around meeting dates of the board of directors. $R^2 = 0.59, 0.59, 0.60,$ and 0.67 for OLS specifications 1–4. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent level, respectively. Standard errors are reported in parentheses. Constant and year dummies not reported.				

readability, all foreign exchange shocks and observed values were summed into quarterly observations. The deterministic component of policy can be interpreted as the difference between the dark shaded and light shaded bars (green and orange bars, respectively, in the online version). As shown, policy shocks greatly differed from observed values, especially during certain time periods. For instance, the left panel of figure 4 shows that the CBRT would have intervened less in the foreign exchange market had it not been for past

Figure 4. Observed Intervention versus New Measures of Policy Shocks: 2002–10



exchange rate movements. Specifically, during 2002–05 and 2007–10, most foreign exchange interventions were explained by the deterministic component of policy. In contrast, interventions in 2005 were highly unpredictable.

In turn, the right panel of figure 4 shows that most policy changes were explained by inflation levels. In this case, changes in inflation explained the variation in the policy rate by almost 65 percent, on average.

One important characteristic of correctly specified policy shocks is their unpredictability. In other words, information prior to the policy change should be uncorrelated with the estimated residuals. A heuristic exercise to test for this orthogonality condition is presented in table 9. Each column denotes a different estimated policy shock, whereas each row contains the different lagged policy intervention. Hence, policy shocks are individually regressed against all of the different types of intervention variables. Values with an “X” correspond to the variable (row) that was included under that specification (column), so the policy shock is, by construction, orthogonal to that variable. As it turns out, all residuals are correctly specified across the various intervention variables.

4.4 Impact on Outcome Variables

We considered four outcome variables in order to evaluate the effects of policy: (i) exchange rate changes, (ii) exchange rate volatility, (iii)

Table 9. Policy Shocks' Orthogonality Condition ($\epsilon_{it} = x'_{it}\beta + \eta_{it}$)

Policy Shock versus Lagged Policies	Unannounced Totals ϵ_{1t}	Unannounced Purchases ϵ_{1t}	Unannounced Sales ϵ_{1t}	Optional Purchases ϵ_{1t}	Announced Purchases ϵ_{1t}	Announced Sales ϵ_{1t}	Policy Rate Changes ϵ_{2t}
Unannounced Totals $_{t-1}$	X	X	X	0.00 (0.002)	0.00 (0.001)	0.00 (0.001)	0.00 (0.001)
Unannounced Purchases $_{t-1}$	X	X	0.00 (0.532)	X	X	X	0.00 (0.001)
Unannounced Sales $_{t-1}$	X	0.00 (0.005)	X	0.00 (0.001)	X	X	X
Optional Purchases $_{t-1}$	0.24 (0.269)	0.29 (0.271)	-0.02 (0.222)	X	0.01 (0.011)	0.00 (0.007)	0.06 (0.178)
Announced Purchases $_{t-1}$	X	-0.23 (0.267)	-0.02 (0.031)	X	X	0.00	X
Announced Sales $_{t-1}$	-0.01 (0.020)	-0.01 (0.017)	-0.03 (0.025)	0.00 (0.001)	0.00 (0.002)	X	-0.00 (0.013)
Policy Rate Changes $_{t-1}$	X	X	X	X	X	X	X

Notes: All models consisted of 2,190 observations. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent level, respectively. Standard errors (robust for OLS) are reported in parentheses.

changes in inflation, and (iv) industrial production growth. In all cases, the effects of both the estimated residuals (ϵ_{1t} , ϵ_{2t}) and the observed policy instruments (FXI_t , IRI_t) were computed.²⁴ While the former consist of correctly specified monetary surprises, the latter are most likely biased by anticipatory movements in the economy. The comparison of both measures is thus useful in order to get a better sense of the direction and magnitude of the bias driven by observed interventions (see equation (3)). Hence, the left panels of figures 5–8 depict responses in outcome variables due to policy shocks. Conversely, the right panels of figures 5–8 depict responses in outcome variables due to observed values of intervention.²⁵

4.4.1 *Exchange Rate Changes (Daily Frequency)*

Panels C and E of figure 5 show significant effects of FX policy shocks on exchange rate changes. Namely, announced purchases of 1 billion USD depreciated domestic currency by up to 5 percent during days 10–40 after the intervention took place. On the other hand, announced sales of 1 billion USD appreciated domestic currency by up to 2.5 percent, but only during the first ten days following the intervention shock. These results are in contrast with most of the recent literature that find non-significant effects of FXI on the exchange rate (see Fischer 2001a, 2001b and Blanchard 2013). However, similar to Rey (2015), we argue that exchange rate effects are possible when breaking free from the monetary trilemma.²⁶

Other FX policy shocks such as unannounced sales and purchases of foreign currency appeared to have a null effect on exchange rate changes.²⁷ Finally, consistent with the theory on interest rate parities, panel G shows that a 1 percent increase in the policy rate shock (IRI shock) appreciates domestic currency by 1 percent during the first month (days 5–25).

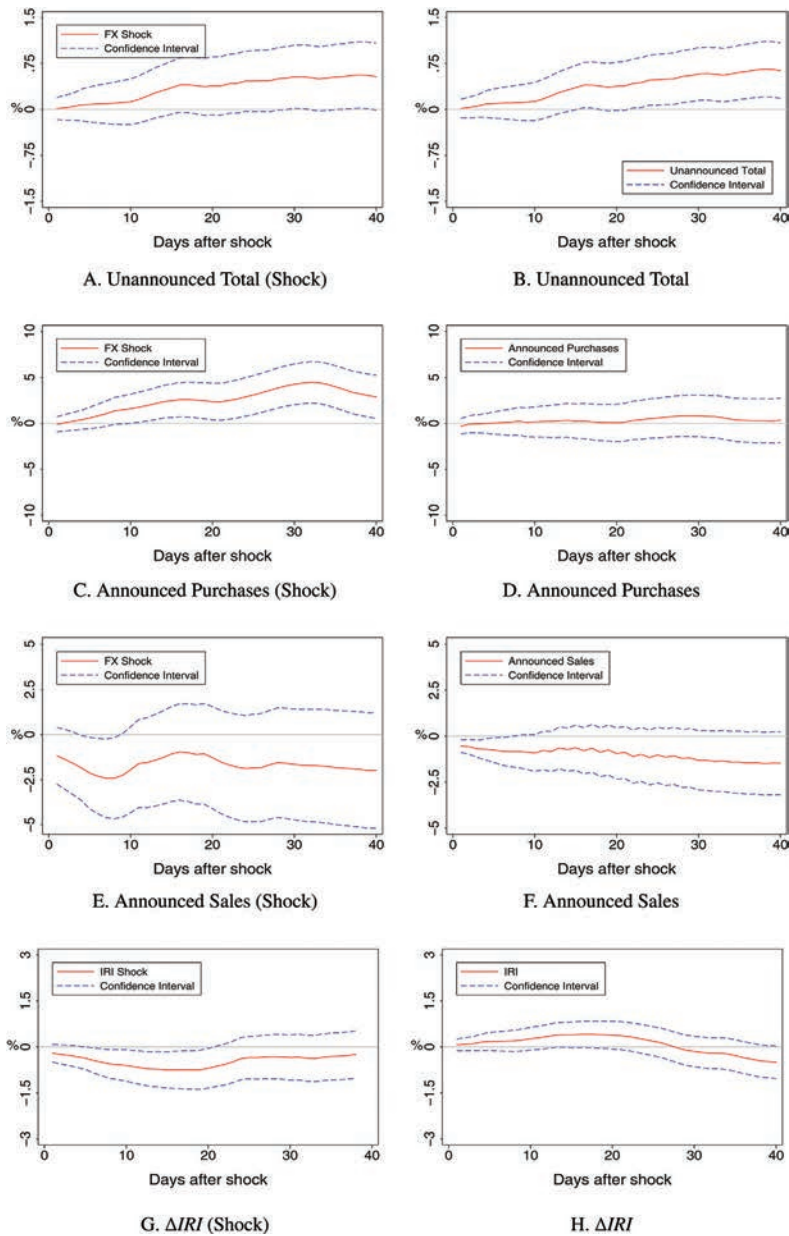
²⁴Policy residuals were computed according to specification 4 of tables 4, 6, and 8, and according to the only specification presented in tables 5 and 7.

²⁵IRFs not reported in figures 5–8 were not statistically significant.

²⁶See Villamizar-Villegas and Perez-Reyna (2017).

²⁷These results are in line with those found in Dominguez (1993), Dominguez and Frankel (1993), Humpage (1999), Kim, Kortian, and Sheen (2000), and Taylor (2004), but are contrary to those found in Disyatat and Galati (2007) and Adler and Tovar (2011).

Figure 5. Implied IRFs of Exchange Rate Changes (Δe_t)



Notes: IRFs A–F correspond to a response in exchange rate changes (%) to a 1 billion USD purchase (or sale). IRFs G–H correspond to a response in exchange rate changes (%) to a 1 percent increase in the policy rate.

4.4.2 *Exchange Rate Volatility (Daily Frequency)*

Figure 6 depicts the implied IRFs of exchange rate volatility. Panels A and C show the effects of an unannounced 1 billion USD purchase and sale, respectively. In both cases, the CBRT was able to stem volatility, although more so for purchases (5.0 percent) than for sales (0.05 percent). But, even though the effect of unannounced sales is small and short-lived, it is at least contrary to the effect found if using observed levels of intervention, as shown in panel D, where volatility increases by almost 15 percent.

Foreign exchange intervention through announced purchases of 1 billion USD also reduces exchange rate volatility by up to 7 percent, as shown in panel E, but effects subside after fifteen days. Finally, panel G shows that changes in the policy rate have no significant impact on exchange rate volatility.

4.4.3 *Changes in Inflation (Monthly Frequency)*

Figure 7 depicts the implied IRFs of changes in inflation. Panel H shows that an increase of 1 percent in the *observed* policy rate change (ΔIRI_t) has a strong and positive effect on inflation (of 1.0 percent) that lasts for more than fifteen months before the effect subsides. Taken at face value, this result is straightforward evidence of the “price puzzle” in which prices and interest rates are positively correlated. However, panel G shows that, just like in Romer and Romer (2004), this bias is completely eliminated: an increase of 1 percent in the policy rate shock lowers inflation by almost 1 percent, and effects are significant only after the first nine months (i.e., months 9–12). This result is in line with the related literature that find evidence of almost a one-year lag delay of interest rates on inflation.²⁸

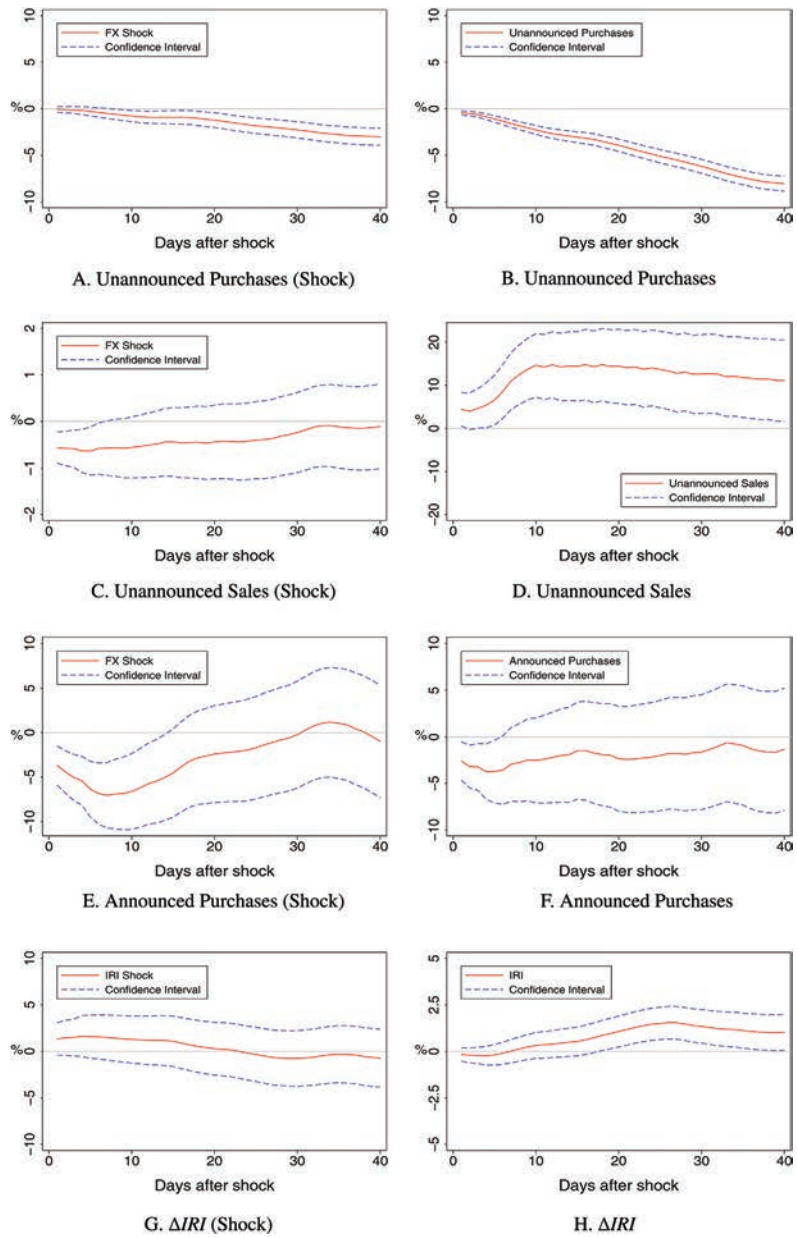
The remaining panels of figure 7 show that foreign exchange shocks have no effects on inflation, which is consistent with the fact that almost all interventions were fully sterilized.

4.4.4 *Industrial Production Growth (Monthly Frequency)*

Figure 8 depicts the implied IRFs of industrial production growth. As shown, only the policy rate shock has a significant effect on

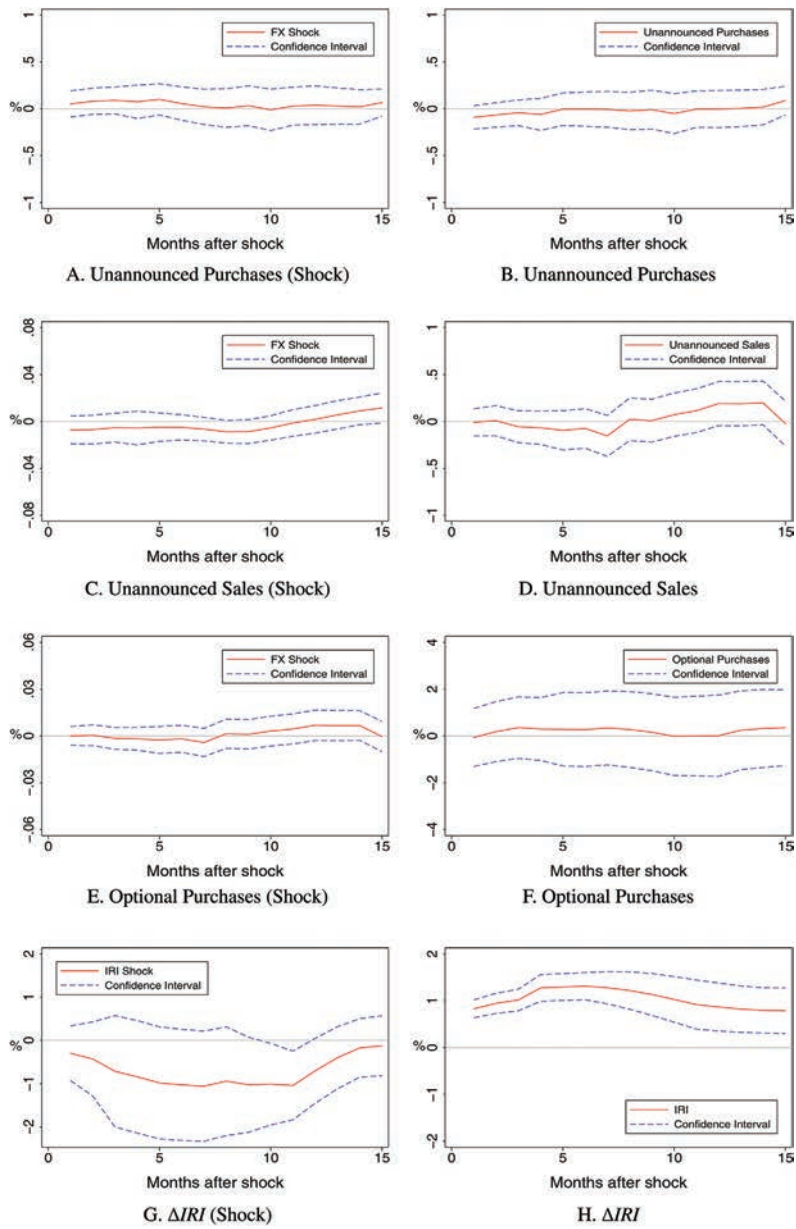
²⁸See, for example, Batini and Nelson (2001), Romer and Romer (2004), and Havranek and Rusnak (2012).

Figure 6. Implied IRFs of Exchange Rate Volatility (Vol_t)



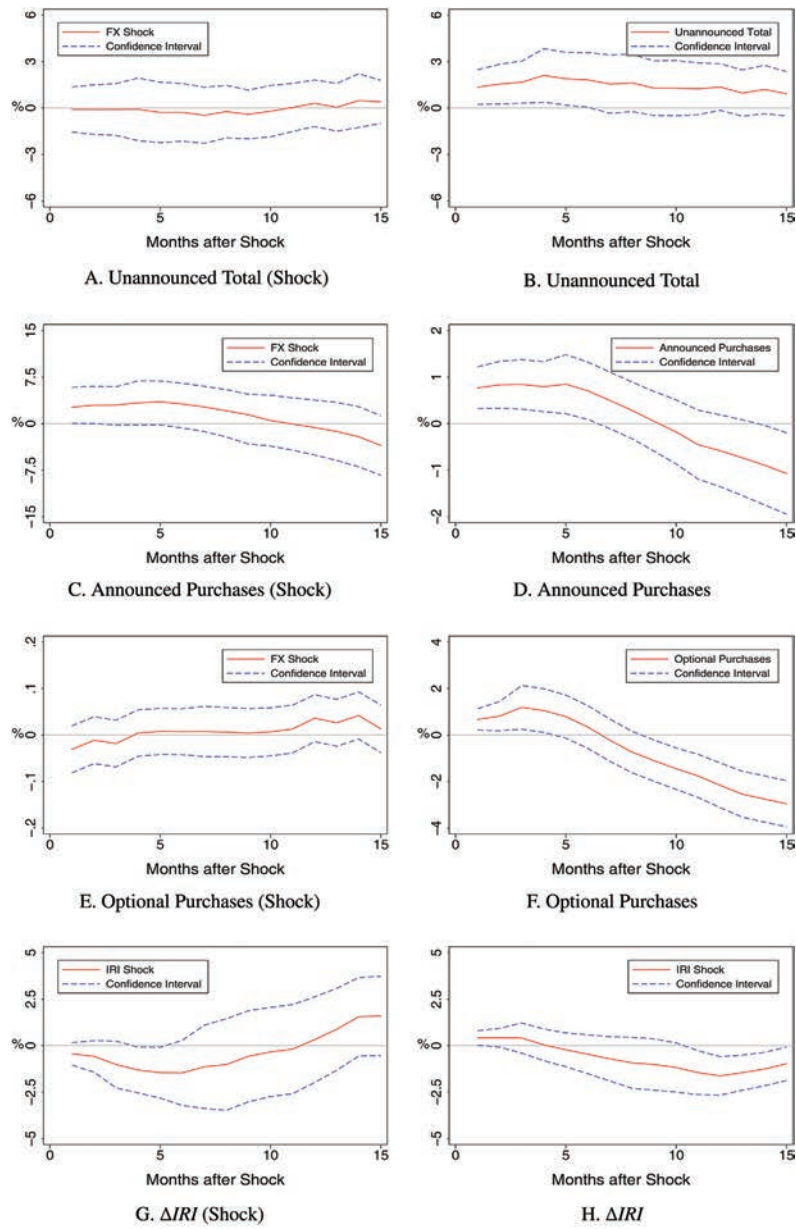
Notes: IRFs A–F correspond to a response in exchange rate changes (%) to a 1 billion USD purchase (or sale). IRFs G–H correspond to a response in exchange rate changes (%) to a 1 percent increase in the policy rate.

Figure 7. Implied IRFs of Inflation Changes ($\Delta\pi_t$)



Notes: IRFs A–F correspond to a response in exchange rate changes (%) to a 1 billion USD purchase (or sale). IRFs G–H correspond to a response in exchange rate changes (%) to a 1 percent increase in the policy rate.

Figure 8. Implied IRFs of Industrial Production (ΔInd_t)



Notes: IRFs A–F correspond to a response in exchange rate changes (%) to a 1 billion USD purchase (or sale). IRFs G–H correspond to a response in exchange rate changes (%) to a 1 percent increase in the policy rate.

industrial output. Namely, panel G shows that a 1 percent increase in the policy rate lowers output growth by up to 2 percent during the second trimester (months 4–6) following a monetary contraction. This result is line with Romer and Romer (2004), Kilinc and Tunc (2014), and Villamizar-Villegas (2016).

4.4.5 *Robustness*

In essence, these results differ from the foreign exchange intervention literature such as Herrera and Ozbay (2005), Geršl and Holub (2006), Humala and Rodriguez (2010), Echavarria et al. (2013), Adler and Tovar (2014), and Kilinc and Tunc (2014), in that we (i) control for the covariance of simultaneous policies, (ii) include only the period in which the CBRT officially adopted an inflation-targeting regime, and (iii) use a different measure of the policy rate.

In terms of the latter (i.e., different measure of policy), we conduct a robustness exercise presented in appendix 3 in which we compare the effects of using the interbank rate on inflation and output.²⁹ As depicted in figure 10 in appendix 3, while the effects of both our measure of policy and the interbank rate follow similar paths, they greatly differ in the size of the standard errors. Consequently, results using the interbank rate show a more immediate (significant) response of policy. We thus believe that factors related to liquidity demand, which in turn are highly correlated with inflation and output, can bias the significance level of the obtained estimates.

5. Conclusions

Following the 2001 crisis, the Turkish economy underwent a structural transformation. The Central Bank of the Republic of Turkey was vested with independence and endowed with the primary objective of achieving and maintaining price stability. In 2002, the CBRT officially adopted an inflation-targeting regime. Concurrently, in order to lower exchange rate volatility, the CBRT conducted foreign exchange interventions in one of two ways: (i) through unannounced

²⁹Similar to Kilinc and Tunc (2014), we use the overnight repo rate obtained from the Istanbul Stock Exchange (Borsa Istanbul) as a measure of the interbank rate.

interventions, often infrequent but large, and (ii) through announced interventions which consisted of predetermined dates and amounts.

In this paper we study the effects of simultaneous central bank policies in a unified framework. Namely, we analyze the effects of both interest rate and foreign exchange intervention on several macroeconomic variables. To this end, we model the undertakings of monetary authorities (tailored to the various foreign exchange mechanisms of the CBRT) and purge the intended monetary decisions from systematic responses of policy. Our investigation confirms some of the previous findings from the literature but also yields some new results. For instance, we find that the price puzzle disappears once monetary shocks are purged from inflation expectations and global financial conditions. Additionally, we find that unannounced purchases of foreign currency had a significant effect in reducing exchange rate volatility but appeared to have no effect on exchange rate changes. Announced interventions, on the other hand, did have a significant impact on exchange rate changes and volatility.

Appendix 1. Data Description

Source: Central Bank of the Republic of Turkey during January 2002–July 2010.

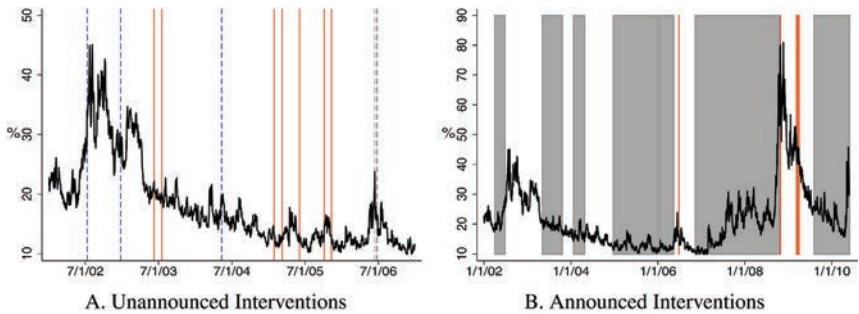
- Policy instruments of the Central Bank of the Republic of Turkey (D_{1t} and D_{2t}):
 - Foreign Exchange Interventions (FXI_t), in millions of U.S. dollars:
 - * Unannounced Purchases and Sales: Exercised through direct sales and purchases of USD.
 - * Announced Purchases and Sales: Sales and purchases of USD with predetermined dates and amounts.
 - * Optional Purchases: During auctions of announced purchases and sales, the CBRT may have exceeded the predetermined amount of FX purchases. There was a limit on how much authorities could exceed during these transactions. The CBRT never optionally exercised sales of USD.
 - Interest Rate Interventions (IRI_t): The policy rate corresponded to the central bank's overnight borrowing rate

between February 20, 2002 and May 16, 2008 (due to the abundant liquidity in the Turkish market); to the overnight lending rate between May 17, 2008 and May 20, 2010 (due to the liquidity shortage); and to the one-week repo lending rate after May 21, 2010. Frequency corresponds to the meeting dates of the board of directors. Units are in changes (%).

- Variables in X_t :
 - Weekly Depreciation (Δe_{t-5}): Weekly (five business days) exchange rate changes. Daily frequency. Units are in log-differences.
 - Monthly Depreciation (Δe_{t-20}): Monthly (twenty business days) exchange rate changes. Daily frequency. Units are in log-differences.
 - U.S. Federal Funds Rate (Δi_t^*): Self-explanatory. Daily frequency. Units are in changes (%).
 - Inflation Surprises ($\pi_t - \pi_t^*$): Expected inflation corresponds to the one-year-ahead forecasts conducted by the CBRT. Biweekly. Units are in (%).
 - Inflation minus Yearly Target ($\pi_t - \pi_t^*$): Self-explanatory. Monthly frequency. Units are in (%).
 - The S&P Goldman Sachs Commodity Price Index, Bloomberg Ticker SPGCCI ($\Delta SPGCCI_t$): Closing price. Daily frequency. Units are in changes (%).
 - VIX Index (VIX_t): Closing price. Daily frequency.
- Outcome Variables in Y_t :
 - Nominal Exchange Rate (e_t): Nominal exchange rate in units of Turkish lira per unit of U.S. dollar (TRY/USD). Daily frequency. Units are in log-differences.
 - Exchange Rate Volatility (Vol_t): Squared daily exchange rate returns (Δe_t). Daily frequency.
 - Industrial Production Growth (ΔInd_t): Industrial production variation. Monthly frequency. Units are in log-differences.
 - Inflation (π_t): Yearly changes for the Turkish Consumer's Price Index (CPI). Monthly frequency. Units are in changes (%).

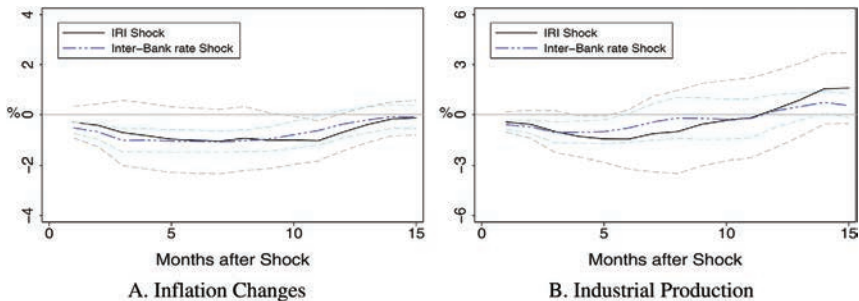
Appendix 2. Global Financial Conditions and FXI

Figure 9. VIX and Foreign Exchange Interventions



Appendix 3. Using Alternative Measures of the Policy Rate

Figure 10. Robustness Exercise: Effects of Using Different Measures of Policy



Notes: IRFs A–B denote a response in inflation (panel A) and industrial output growth (panel B) to a 1 percent increase in the policy rate.

Appendix 4. Statistical Properties

Table 10. Elliott-Rothenberg-Stock Test for Unit Root

Variable (up to 28 Lags)	t-statistic	1% Critical Value	10% Critical Value
Unannounced FX Purchases _t	−33.064	−3.480	−2.570
Unannounced FX Sales _t	−10.255	−3.480	−2.570
Announced FX Purchases _t	−3.771	−3.480	−2.570
Announced FX Sales _t	−10.911	−3.480	−2.570
Optional FX Purchases _t	−3.808	−3.480	−2.570
Policy Rate (ΔIRI_t)	−6.631	−3.480	−2.570
Inflation ($\Delta \pi_t$)	−4.183	−3.480	−2.570
Inflation (π_t) – Expected (π_t^e)	−2.648	−3.480	−2.570
Inflation (π_t) – Target (π_t^*)	−2.640	−3.480	−2.570
Exchange Rate (Δe_t)	−8.201	−3.480	−2.570
Monthly Exchange Rate (Δe_{t-20})	−6.361	−3.480	−2.570
Exchange Rate Volatility (Vol_t)	−5.916	−3.480	−2.570
Industrial Production (ΔInd_t)	−3.066	−3.480	−2.570
U.S. Federal Funds Rate (Δi_t^*)	−9.476	−3.480	−2.570
Commodity Price Index ($\Delta SPGCCI_t$)	−7.837	−3.480	−2.570
VIX Index _t	−2.816	−3.480	−2.570
Notes: The minimum lag is determined using the modified Akaike information criterion (MAIC). All variables reject the null hypothesis of a unit root at the 1 percent level (except for industrial production growth, inflation minus its yearly target, inflation minus its yearly forecast, and the VIX index, which reject the null at the 0 percent level).			

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Monetary and Macroprudential Policies to Manage Capital Flows*

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We study interactions between monetary and macroprudential policies in a model with nominal and financial frictions. The latter derive from a financial sector that provides credit and liquidity services that lead to a financial accelerator-cum-fire-sales amplification mechanism. In response to fluctuations in world interest rates, inflation targeting neutralizes nominal distortions but leads to increased volatility in credit and asset prices. Taylor rules do better, but the use of a counter-cyclical macroprudential instrument in addition to the policy rate improves welfare and has important implications for the conduct of monetary policy. “Leaning against the wind” or augmenting a Taylor rule with an argument on credit growth is not an optimal policy response.

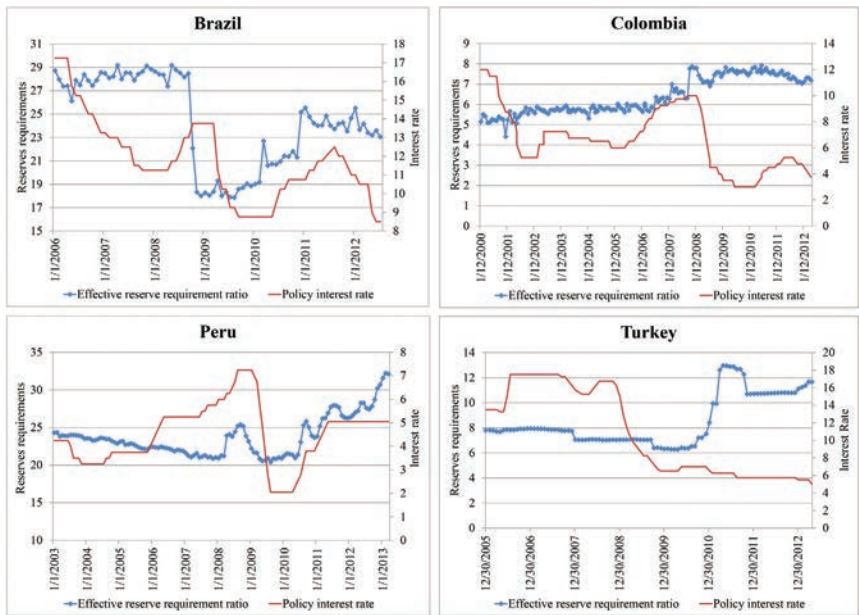
JEL Codes: E44, E52, E61, F41.

1. Introduction

One of the legacies of the recent financial crisis has been a shift toward a systemwide or macroprudential approach to financial supervision and regulation (Bernanke 2008; Blanchard, Dell’Ariccia, and Mauro 2010). By their own nature, macroprudential policies that have a systemic and cyclical approach are bound to affect macroeconomic variables beyond the financial sector and interact with other macro policies, especially monetary policy (Caruana 2011; International Monetary Fund 2013a). In this paper, we study

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Figure 1. Interest Rates and Reserve Requirements in Selected Emerging Markets



these interactions, focusing on the distortions that these policies attempt to mitigate, especially in the management of swings in capital flows (Ostry et al. 2011).

A number of emerging market economies have recently used macroprudential instruments countercyclically to deal with swings in capital flows. Lim et al. (2011) document this for a number of macroprudential instruments, and Federico, Vegh, and Vuletin (2014) do it for reserve requirements.¹ Figure 1 shows the countercyclical use of reserve requirements for four emerging markets around Lehman’s bankruptcy (see also IMF 2012). All four countries slashed policy rates in the immediate aftermath of Lehman’s bankruptcy, but Brazil and Peru reduced reserve requirements dramatically even

¹Elliot, Feldberg, and Lehnert (2013) provide a comprehensive survey of the historical evidence on the use of cyclical macroprudential instruments in the United States, including underwriting standards, reserve requirements, credit growth limits, deposit rate ceilings, and supervisory pressure.

before cutting rates. As capital inflows surged following the adoption of unconventional monetary policies in the major reserve-currency-issuing countries, all four countries raised reserve requirements to curb credit growth, and they increased policy rates—with the exception of Turkey.²

These policy responses and the crisis itself have opened an intense debate about objectives, targets, and instruments of both monetary and macroprudential policies. Most papers addressing these issues assume that the government's objective is to minimize a loss function that adds credit growth volatility to that of output and inflation, and rank policies accordingly (see, for instance, Glocker and Towbin 2012; Mimir, Sunel, and Taskin 2013; Suh 2014). They usually find that macroprudential instruments contribute to price and financial stability, especially when dealing with financial shocks, but that there are tradeoffs between monetary and macroprudential instruments with respect to demand or productivity shocks. Kannan, Rabanal, and Scott (2012) and Unsal (2013) also rank these policies according to the volatility of inflation and the output gap, and do not derive the impact of the macroprudential measures from financial frictions but rather postulate that the measures lead to an additional cost for financial intermediaries. Quint and Rabanal (2014) and Bailliu, Meh, and Zhang (2015) do welfare analysis (rather than postulate an arbitrary loss function), but still their financial frictions are postulated in an ad hoc way (without fully modeling the incentive problems behind the frictions).

In this paper we study interactions between monetary and macroprudential policies and we innovate on three fronts. First, we model explicitly and with *microfoundations* the nominal and financial frictions that monetary and macroprudential policies attempt to mitigate. In particular, we incorporate a financial sector that provides both credit and liquidity services following standard contracting and optimization problems.³ Second, we calculate model-based *welfare measures* for different policy arrangements and rank them

²Changes in average reserve requirements in Colombia underestimate the actual impact because they do not capture changes in marginal rates and remuneration that increase the effectiveness of these measures (Vargas et al. 2010).

³Di Iasio and Quagliariello (2013) show that a microprudential regulatory regime that disregards the equilibrium effect of asset prices on incentives performs poorly in a micro model with endogenous liquidation of assets under distress.

accordingly. And third, we focus on a *shock to world interest rates*, which keeps rates low for an extended period of time and which is later on undone (rather than the standard AR(1) processes). This induces a long period of capital inflows followed by a reversal that resembles the unwinding of unconventional monetary policies in advanced economies. Thus, we study the interactions of these two policies during an event that is relevant for many countries at this juncture and where the potential tradeoffs between these two policies are least understood.⁴

The financial sector in our model features two types of representative intermediaries that operate in competitive markets: a lending and a liquidity intermediary, which interact with each other through an interbank market. The lending intermediary provides credit to entrepreneurs, solving an agency-cost problem as in Bernanke, Gertler, and Gilchrist (1999). For the liquidity intermediary, we extend the mechanism introduced by Choi and Cook (2012), and assume that liquidity services are produced with “excess reserves” and real resources.⁵ This assumption provides natural links between the lending intermediaries and with the monetary authority, and allows us to endogenize not just default but also recovery rates, as well as the response to a countercyclical macroprudential instrument. Although the model does not deliver the type of systemic events (crises) that macroprudential policies aim to mitigate, the financial accelerator-cum-fire-sales mechanism we introduce produces a fair amount of amplification and persistence that makes the financial friction relevant for macroeconomic policies—in particular, to study interactions between monetary and macroprudential policies.⁶

⁴The importance of shocks to world interest rates for emerging market business cycles has been emphasized in Neumeyer and Perri (2005).

⁵In Choi and Cook (2012), liquidity services are provided by non-financial firms, which makes it hard to relate to macroprudential policies. Breaking up intermediaries according to functions is a useful theoretical (Merton and Bodie 2004) and macro-modeling device (Gerali et al. 2010).

⁶The class of models with occasionally binding collateral constraints (Jeanne and Korinek 2010; Benigno et al. 2013; Bianchi and Mendoza 2013) allows for a definition of “crises” as the states of the world when the constraint is binding. For a study of optimal monetary policy when collateral constraints are binding (i.e., “crisis” episodes), see Braggion, Christiano, and Roldós 2009.

This financial sector is embedded in an otherwise-standard small open-economy New Keynesian model with Calvo-pricing nominal rigidities (as in Galí and Monacelli 2005). We study the transitional dynamics to the world interest rate shock and also derive a welfare function consistent with the underlying model, where tradeoffs between correcting both distortions may exist. As in Faia and Monacelli (2007), we study a restricted set of rules that we can rank according to that welfare metric. In particular, we consider Taylor-type rules, both standard and augmented with a credit growth argument (as in Christiano et al. 2010), and combine them with both a constant and a countercyclical reserve requirement—our simple macroprudential rule.

A large and protracted reduction in world interest rates produces large capital inflows and increases in aggregate demand, activity, the real exchange rate, and asset prices in what we call the “natural” economy—i.e., the one without price or financial frictions. The introduction of these frictions magnifies the cyclical fluctuations of most macro and financial variables—in particular, of asset prices and credit.

Our main results are the following. First, even though a pure or strict inflation-targeting (IT) regime neutralizes the nominal frictions in the model, it delivers too much asset price and credit volatility; thus, a standard or an adjusted Taylor rule that reacts to credit growth (as suggested by Christiano et al. 2010) neutralizes in part, albeit indirectly, the financial frictions, improving welfare relative to the IT regime. However, all these regimes are dominated in welfare terms by one that utilizes a countercyclical reserve requirement (aimed at the financial friction) together with a pure IT rule for monetary policy (aimed at the nominal friction). We interpret this result as reflecting the Tinbergen principle of “one instrument for each objective” and Mundell’s “principle of effective market classification,” whereby instruments should be paired with the objectives on which they have the most influence (see Beau, Clerc, and Mojon 2012 and Glocker and Towbin 2012).

Second, we show that “leaning against the wind” of financial instability—by, say, having the monetary policy rate respond to credit growth—may be a suboptimal solution. Third, once we use a macroprudential instrument in a countercyclical fashion, the evolution of the policy rate deviates substantially from the Taylor rule

and suggests the need for close coordination of both instruments. In particular, while the “natural” interest rate of this economy declines with the world rate, the policy rate may indeed need to be increased to accommodate reserve requirements—in contrast to the Turkey experience in figure 1.

The paper is organized as follows. The next section lays out the model economy, with special focus on the financial sector, and describes the four monetary and macroprudential policy frameworks. Section 3 discusses a baseline calibration and the welfare measure we use to rank these policy frameworks. Section 4 studies the policy responses to the proposed world interest rate shocks, analyzing impulse responses and welfare rankings, followed by section 5 on the robustness of the results. Section 6 concludes the paper. The appendixes provide technical details on the model derivations and extensions.

2. Model Economy

The model is an extension of the financial accelerator framework developed by Bernanke, Gertler, and Gilchrist (1999), henceforth BGG, to an open-economy context. The presence of price rigidities induces a role for monetary policy to affect the real interest rate and correct the associated distortion. Similarly, the presence of a financial friction associated with the cost of monitoring defaulted borrowers suggests the potential role of a macroprudential instrument to reduce this other distortion. In addition to the BGG credit friction, we extend the mechanism in Choi and Cook (2012) whereby fire sales further amplify the financial accelerator mechanism. In Choi and Cook (2012), when a loan is defaulted, the capital seized by the lending intermediaries is sold at a discounted price due to the fact that the liquidation technology consumes resources. In this paper, we assume that, in addition to the use of real resources, the liquidation process also requires time and excess reserves in the financial sector, which produces a natural real-financial linkage and a role for reserve requirements to manage the intensity of the financial cycle.

In what follows we explain in more detail the different agents and their behavior in our model economy: households, capital and goods producers, entrepreneurs, and the financial sector.

2.1 Households

The intertemporal preferences of the households are characterized by

$$U_t = E_t \left[\sum_{i=0}^{\infty} \beta^i u \left(c_t, h_t, \frac{M_t}{P_t} \right) \right],$$

where c_t is the consumption basket, h_t is labor supply, and M_t/P_t are real money balances. The period- t household budget constraint equals consumption plus savings with real income:

$$\begin{aligned} c_t + \frac{D_t}{P_t} - \frac{e_t B_{H,t}^*}{P_t} + \frac{M_t}{P_t} = & \frac{W_t}{P_t} h_t + R_{t-1}^D \frac{D_{t-1}}{P_t} - R_{t-1}^* \Theta_{t-1} \frac{e_t B_{H,t-1}^*}{P_t} \\ & + \frac{M_{t-1}}{P_t} + \Pi_t - \tau_t. \end{aligned}$$

Household savings can be invested in three types of financial assets: deposits (D_t) with a return of R_t^D in t ; foreign bonds ($B_{H,t}^*$) with a foreign currency return $R_t^* \Theta_t$ in t ; and money balances (M_t). The household's income in period t derives from labor, returns from previous periods' holding of financial assets, and profits from firms Π_t (net of lump-sum taxes, τ_t).

Foreign bonds are expressed in foreign currency and e_t is the nominal exchange rate (units of domestic currency per unit of foreign currency). Θ_t is a risk premium for foreign bonds (liabilities), which is taken as given by the households, but is a function of the total indebtedness of the economy, $\Theta_t = \Theta(B_t^*)$. The real exchange rate is defined as $rer_t = e_t P_t^*/P_t$.

The optimal holding of deposits satisfies the following households' Euler equation:

$$1 = \beta R_t^D E_t \left[\frac{u_{c,t+1}}{u_{c,t}} \frac{1}{(1 + \pi_{t+1})} \right]. \quad (1)$$

The optimal holding of foreign bonds (liabilities) satisfies the following households' Euler equation:

$$1 = \beta R_t^* \Theta(B_t^*) E_t \left[\frac{u_{c,t+1}}{u_{c,t}} \frac{rer_{t+1}}{rer_t} \frac{1}{(1 + \pi_{t+1}^*)} \right]. \quad (2)$$

The money demand by households is given by

$$u_{\frac{M}{P},t} = \frac{R_t^D - 1}{R_t^D} u_{c,t}, \quad (3)$$

and households' labor supply is characterized by

$$\frac{W_t}{P_t} = -\frac{u_{h,t}}{u_{c,t}}. \quad (4)$$

In this economy, households save in financial assets, but they don't manage the allocation and financing of the physical capital stock.

2.2 Production and Capital Accumulation

Competitive firms in this economy produce domestic goods (that are sold to domestic and foreign wholesalers) and capital goods (that are sold to entrepreneurs). Aggregate production of domestic goods is given by

$$y_t = a_t(k_t)^{\theta_y}(h_t)^{1-\theta_y}, \quad (5)$$

which is sold at price $P_{y,t}$. The demand for labor and the demand for capital services are given by

$$\frac{W_t}{P_t} = \frac{P_{y,t}}{P_t} \frac{(1 - \theta_y)Y_t}{h_t}, \text{ and} \quad (6)$$

$$\frac{VMPK_t}{P_t} = rr_{K,t} = \frac{P_{y,t}}{P_t} \frac{\theta_y y_t}{k_t}, \quad (7)$$

where $VMPK_t$ and $rr_{K,t}$ are the nominal marginal productivity of capital and the real rental rate of capital, respectively. Capital is produced by perfectly competitive capital producers that buy installed capital from successful entrepreneurs, new capital from goods producers, and liquidated or restructured capital from liquidity intermediaries.

In contrast to the standard financial accelerator model (BGG 1999), we assume that defaulted capital requires time and resources to be liquidated and become productive again. Let $k_{D,t}$ and $k_{D,t}^{new}$ be, respectively, the stock of defaulted capital and the new defaulted

capital in period t . Both the productive and defaulted capital depreciate at a rate δ . Each period, there is a probability η_K of turning one unit of defaulted capital into a productive one. In consequence, a fraction η_K of the undepreciated defaulted capital becomes productive. Thus, the evolution of the productive capital stock is given by

$$k_{t+1} = (1 - \delta)(k_t - k_{D,t}^{new}) + \left(1 - \Delta\left(\frac{inv_t}{inv_{t-1}}\right)\right) inv_t + \eta_K(1 - \delta)k_{D,t}, \quad (8)$$

where $\Delta(\cdot)$ is an adjustment cost in the change of investment that can be interpreted as a time-to-build mechanism for capital accumulation. From the capital-goods-producer problem we obtain the demand for investment (new capital):

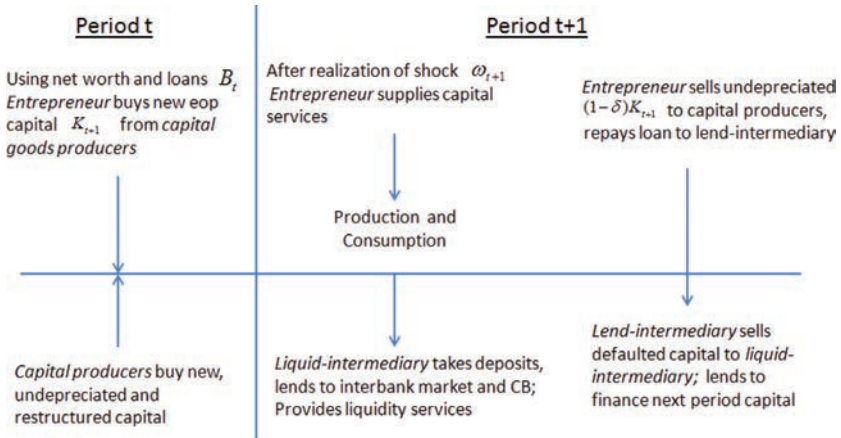
$$qr_t \left(1 - \Delta\left(\frac{inv_t}{inv_{t-1}}\right) - \Delta'\left(\frac{inv_t}{inv_{t-1}}\right) \frac{inv_t}{inv_{t-1}}\right) + E_t \left[sd_{t,t+1} qr_{t+1} \left(\Delta'\left(\frac{inv_{t+1}}{inv_t}\right) \left(\frac{inv_{t+1}}{inv_t}\right)^2 \right) \right] = 1, \quad (9)$$

where $sd_{t,t+1}$ is the stochastic discount factor between period t and $t + 1$ (the household intertemporal marginal rate of substitution of consumption, $sd_{t,t+1} = \beta u_{c,t+1}/u_{c,t}$), and $Q_t(qr_t)$ is the nominal (real) price of installed capital.

2.3 Financial Sector

The financial sector links depositors (households) and investors (entrepreneurs). It comprises two sets of intermediaries—lending and liquidity intermediaries—which interact through an interbank market and summarize the provision of credit and liquidity services in this economy.⁷ In laying out this generic financial system, we follow Merton and Bodie (2004) and focus on the two key functions of providing credit and liquidity, while leaving the more specific institutional details to the calibration exercise—and the specifics of

⁷It is not uncommon in macroeconomic models to split the financial system into segments: Gerali et al. (2010), for instance, split the banking system into two “retail” branches and one “wholesale” unit.

Figure 2. Timing of Events

different actual economies. Entrepreneurs in this economy use their nominal net worth ($netn_t$) and loans (B_t) from the lending intermediaries to purchase new, installed physical capital, k_{t+1} , from capital producers. Entrepreneurs then experience an idiosyncratic technological shock that converts the purchased capital into $\omega_{t+1}k_{t+1}$ units at the beginning of the period (where ω_{t+1} is a unit-mean, log-normally distributed random variable with standard deviation equal to σ_ω), and rent capital to goods producers. If they are successful, entrepreneurs sell their capital to capital producers at the end of the period and repay their loans. If they are unsuccessful and default, the lending intermediary takes control of the capital and sells (at a fire-sale price) the capital to the liquidity intermediary, which uses real and financial resources to restructure and sell it back to capital producers (the timeline of events is summarized in figure 2).

2.3.1 Lending Intermediaries

Lending intermediaries get funds from the interbank market and lend them to entrepreneurs through BGG-type debt contracts. Since only the entrepreneurs observe the realization of the shock, they have an incentive to misrepresent the outcome, and this creates an agency-cost distortion that the debt contract attempts to minimize.

For each unit of capital, a successful entrepreneur obtains a nominal payoff equal to the rental rate of capital and the price of the undepreciated capital:

$$payn_t = P_t(rr_{K,t} + (1 - \delta)qr_t) = VMPK_t + (1 - \delta)Q_t. \quad (10)$$

The contracts are characterized by a lending interest rate, R_{t+1}^l , such that if the entrepreneur has a realization of ω_{t+1} and $\omega_{t+1}payn_{t+1}k_{t+1} \geq R_{t+1}^l B_t$, he pays back the loan in full to the lending intermediaries; if the realization falls short ($\omega_{t+1}payn_{t+1}k_{t+1} < R_{t+1}^l B_t$), the entrepreneur defaults on the loan.

It is convenient to define the *average* rate of return of capital as

$$R_{t+1}^K = \frac{VMPK_{t+1} + (1 - \delta)Q_{t+1}}{Q_t}. \quad (11)$$

At the end of period t the entrepreneur has net worth N_t and borrows B_t from the lending intermediary to buy k_{t+1} . An endogenous cutoff $\bar{\omega}_{t+1}$ determines which entrepreneurs repay and which ones default, and it is determined by the expression

$$\bar{\omega}_{t+1}R_{t+1}^K Q_t k_{t+1} = R_{t+1}^l B_t. \quad (12)$$

This equation implies that, *ceteris paribus*, the lending rate R_{t+1}^l moves with the cutoff $\bar{\omega}_{t+1}$. Thus, instead of characterizing the loan contract in terms of R_{t+1}^l , we can do it in terms of $\bar{\omega}_{t+1}$.

When the entrepreneur defaults, the lending intermediary audits and takes control of the investment, which then is sold to the liquidity intermediary. In this case, the lending intermediaries still obtain the benefit of renting capital to output producers, but the default has costs due to the fact that the undepreciated capital is sold at a nominal (real) fire-sale price FS_t ($fsr_t = FS_t/P_t$). Thus, the actual payment that a lending intermediary can obtain from a defaulted loan ($\omega_t < \bar{\omega}_t$) is $\omega_t k_t (VMPK_t + FS_t)$.

The lending intermediary determines the cutoff $\bar{\omega}_t$ with the zero-profit condition:

$$(1 - \Phi(\bar{\omega}_t; \sigma_\omega))R_t^l B_{t-1} + k_t(VMPK_t + (1 - \delta)FS_t) \times \int_0^{\bar{\omega}_t} \omega d\Phi(\omega; \sigma_\omega) = R_{t-1}^{IB} B_{t-1}, \quad (13)$$

where $\Phi(\omega_t; \sigma_\omega)$ is the cumulative probability distribution (CDF) of ω_t given its standard deviation σ_ω , R_{t-1}^{IB} is the gross cost of funds, and B_{t-1} is nominal borrowing. Using the relationship between R_{t-1}^l and $\bar{\omega}_t$, we can define the cost of default as

$$\mu_t = \frac{(Q_t - FS_t)(1 - \delta)}{payn_t}. \quad (14)$$

In contrast to BGG (1999), who assume a constant μ_t , here the cost of default is endogenous and depends on the difference between the market prices of installed and defaulted capital. Under financial stress, fire-sale prices differ substantially from the price of installed capital, decreasing recovery values and increasing the cost of default.

Thus, we can define the share of $payn_t k_t$ going to the lending intermediaries as

$$g(\bar{\omega}_t, \mu_t, \sigma_\omega) = \bar{\omega}_t(1 - \Phi(\bar{\omega}_t; \sigma_\omega)) + (1 - \mu_t) \int_0^{\bar{\omega}_t} \omega d\Phi(\omega; \sigma_\omega) \quad (15)$$

and the share of $payn_t k_t$ going to entrepreneurs as

$$f(\bar{\omega}_t, \sigma_\omega) = \int_{\bar{\omega}_t}^{\infty} \omega d\Phi(\omega; \sigma_\omega) - \bar{\omega}_t(1 - \Phi(\bar{\omega}_t; \sigma_\omega)). \quad (16)$$

The optimal conditions for the loan contract that maximizes the entrepreneur payoff, subject to the lending intermediary zero-profit condition, are the following (see appendix 1 for details):

$$\begin{aligned} Q_t E_t \left\{ R_t^{IB} \frac{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_\omega)}{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \right\} \\ = E_t \left\{ \frac{payn_{t+1}}{\rho(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \frac{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_t)}{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \right\}, \end{aligned} \quad (17)$$

which represents an arbitrage condition for the loans to entrepreneurs, and the breakeven condition for financial intermediaries:

$$g(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega) payn_{t+1} k_{t+1} = R_t^{IB} B_t. \quad (18)$$

In expression (17), $\rho(\cdot)$ can be interpreted as a risk premium, and it is defined as

$$\rho(\bar{\omega}_t, \mu_t, \sigma_\omega) = \left[g(\bar{\omega}_t, \mu_t, \sigma_\omega) - f(\bar{\omega}_t, \sigma_\omega) \frac{g_{\bar{\omega}}(\bar{\omega}_t, \mu_t, \sigma_\omega)}{f_{\bar{\omega}}(\bar{\omega}_t, \sigma_\omega)} \right]^{-1}. \quad (19)$$

In order to describe the evolution of the entrepreneurs' net worth, we will assume that a fraction $1 - \lambda$ of entrepreneurs survive to the next period while the rest (a fraction λ) die and consume all their wealth. The dead entrepreneurs are replaced by a new mass of entrepreneurs that start with a real net wealth equal to τ_E . For simplicity, we will consider that the surviving entrepreneurs also receive this real net wealth transfer. Thus, the net worth of entrepreneurs evolves according to

$$netn_t = (1 - \lambda)f(\bar{\omega}_t, \sigma_\omega)payn_t k_t + P_t \tau_E, \quad (20)$$

and the dying entrepreneurs have the following consumption:

$$c_{K,t} = \lambda f(\bar{\omega}_t, \sigma_\omega) \frac{payn_t}{P_t} k_t. \quad (21)$$

2.3.2 Liquidity Intermediaries

Liquidity intermediaries receive deposits from households paying a gross rate R_t^D , and lend in the interbank market at an interest rate R_t^{IB} (and to the monetary authority at a rate R_t^{RE}). They use “excess reserves” and final goods to provide liquidity services that amount to liquidating or restructuring the capital of unsuccessful entrepreneurs.⁸

We assume that the demand for liquidation services is related to the stock of defaulted capital:

$$lq_t = vk_{D,t}. \quad (22)$$

The evolution of defaulted capital is given by

$$k_{D,t+1} = (1 - \eta_K)(1 - \delta)k_{D,t} + k_{D,t+1}^{new}, \quad (23)$$

⁸Real resources are needed to conduct due diligence, assess future cash flows of failed capital, and return it to productive use. “Excess reserves” are the financial or liquid resources needed to buy that capital or distressed assets. As noted by Gorton and Huang (2004), there are many notions of “liquidity,” and they mostly refer to situations where not all assets can be used to buy all other assets at a point in time. This amounts to a “liquidity-in-advance” constraint, as summarized in the technology below.

where $k_{D,t+1}^{new}$ is the amount of new defaulted capital at the end of period $t + 1$,

$$k_{D,t+1}^{new} = k_{t+1} \int_0^{\bar{\omega}_{t+1}} \omega d\Phi(\omega; \sigma_\omega). \quad (24)$$

Liquidity intermediaries provide these liquidity services using a technology that combines excess reserves and final goods in a complementary way:⁹

$$lq_t = \min[Z(n_t)^{1-\alpha_{lq}}; \quad Z_{xr}(xr_t)^{1-\alpha_{xr}}]. \quad (25)$$

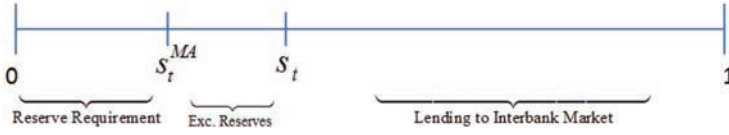
Thus, the problem of the liquidity intermediaries is to maximize current profits from lending to interbank markets and to the monetary authority as well as producing other liquidity services.¹⁰

$$\begin{aligned} \max_{n_t, s_t, (\frac{D_t}{P_t})} & \left\{ [(1 - s_t)R_t^{IB} + s_t^{MA}R_t^{RE} - R_t^D] \frac{D_t}{P_t} \frac{P_t}{R_t^D} - P_t n_t \right\} \\ \text{s.t. } lq_t &= Z(n_t)^{1-\alpha_{lq}} \\ lq_t &= Z_{xr}(xr_t)^{1-\alpha_{xr}} \\ xr_t &= (s_t - s_t^{MA}) \frac{D_t}{P_t}, \end{aligned}$$

where (D_t/P_t) is the real amount of deposits, a fraction $(1 - s_t)$ of which is lent in the interbank market. The monetary authority imposes a reserve requirement of s_t^{MA} , and xr_t are excess reserves used in liquidation services (see figure 3). Since the opportunity cost of funding for liquidity intermediaries is R_t^D , they discount the end-of-period net benefits of lending in the interbank market by this interest rate.

⁹The use of reduced-form technologies to produce financial services is common in monetary policy models (see, for instance, Chari, Christiano, and Eichenbaum 1995; Edwards and Vegh 1997; Goodfriend and McCallum 2007; Christiano, Motto, and Rostagno 2010; and Cúrdia and Woodford 2010). It is important for financial resources to be needed in the liquidation services to relate these to fire sales, but our results still go through when some degree of substitution between real and financial resources is allowed.

¹⁰The full dynamic problem of the liquidity intermediary is presented in appendix 2.

Figure 3. Liquidity Intermediary Allocation Problem

Optimality conditions for the liquidation services determine the fire-sale price of defaulted capital (see appendix 2):

$$FS_t = \eta_K Q_t - \nu(f_t + g_t) + (1 - \eta_K)(1 - \delta)E_t \left[\frac{sd_{t,t+1}}{1 + \pi_{t+1}} FS_{t+1} \right], \quad (26)$$

where f_t and g_t are the marginal costs of liquidation services attributed, respectively, to the use of final goods and excess reserves. These marginal costs of liquidation services are an important determinant of the spread between the interbank and deposit rates:

$$R_t^{IB} = \frac{g_t}{P_t} \frac{(1 - \alpha_{lq})lq_t}{xr_t} R_t^D. \quad (27)$$

This spread can also be expressed in terms of the macroprudential policy instrument, the time-varying reserve requirement s_t^{MA} (assuming $R_t^{RE} = 1$):

$$R_t^{IB} = (1 - s_t^{MA})^{-1} [R_t^D - s_t^{MA}]. \quad (28)$$

Finally, equilibrium in the interbank market means that the fraction of entrepreneurs' debt financed in the interbank market has to be equal to the fraction of real deposits of the liquidity intermediaries lent in the interbank market:

$$\frac{D_t}{P_t} (1 - s_t) = \frac{B_t}{P_t}. \quad (29)$$

2.4 Aggregation and Price Rigidities

Total demand for final goods is given by

$$da_t = c_t + c_{K,t} + inv_t + n_t, \quad (30)$$

where final goods are a composite of domestic and imported goods.¹¹

$$y_{s,t} = [(1 - \alpha_d)^{1/\theta_d} (y_t - x_t)^{1-1/\theta_d} + (\alpha_d)^{1/\theta_d} (y_{f,t})^{1-1/\theta_d}]^{\frac{\theta_d}{\theta_d-1}}, \quad (31)$$

where x_t are exports of domestically produced goods while $y_{f,t}$ are imports of foreign goods.

The real marginal cost of final goods is given by (α_d is the share of foreign goods)

$$mgcr_t = \left[(1 - \alpha_d) \left(\frac{P_{y,t}}{P_t} \right)^{1-\theta_d} + (\alpha_d) (rer_t)^{1-\theta_d} \right]^{\frac{1}{1-\theta_d}}, \quad (32)$$

and the relative demand for domestic and imported goods in the final good basket is

$$\frac{y_t - x_t}{y_{f,t}} = \frac{(1 - \alpha_d)}{\alpha_d} \left(\frac{rer_t}{P_{y,t}/P_t} \right)^{\theta_d}, \quad (33)$$

where rer_t is the real exchange rate as defined previously, and θ_d is the elasticity of substitution between domestic and foreign goods in the composite good.

The wholesale firms that produce differentiated domestic goods operate in monopolistically competitive markets and set prices à la Calvo (1983). Thus, in each period only a fraction $1 - \phi_p$ of the firms can change optimally their prices while all other firms can adjust the price according to a fraction $\chi_p \in [0, 1]$ of past inflation. A log-lineal version of the Phillips curve of final good inflation is (see appendix 3 for a complete derivation of the conditions)

$$\begin{aligned} \log(1 + \pi_t) &= \frac{\beta}{1 + \beta\chi_p} E_t [\log(1 + \pi_{t+1})] + \frac{\chi_p}{1 + \beta\chi_p} \log(1 + \pi_{t-1}) \\ &+ \frac{(1 - \phi_p)(1 - \beta\phi_p)}{\phi_p(1 + \beta\chi_p)} \log\left(\frac{mgcr_t}{MC}\right). \end{aligned} \quad (34)$$

¹¹Details of the aggregation and the role of price-setting wholesalers can be found in appendix 3.

Finally, the balance-of-payments identity implies that

$$rer_t B_t^* = R_{t-1}^* \Theta(B_{t-1}^*) \frac{B_{t-1}^*}{(1 + \pi^*)} rer_t - \frac{P_{y,t}}{P_t} x_t + rer_t (y_{f,t}), \quad (35)$$

where $B_t^* = B_{H,t}^*$ is the stock of foreign debt of the economy, R_t^* is the (gross) foreign interest rate, and π^* is the foreign inflation rate.

The foreign demand for exports is modeled as

$$x_t = \bar{x} \left(\frac{rer_t}{P_{y,t}/P_t} \right)^{\theta^*}, \quad (36)$$

where θ^* is the price elasticity of the foreign demand for domestic goods, and the exogenous evolution of the foreign interest rate is given by the following stochastic process:

$$\log \left(\frac{R_{t+1}^*}{R^*} \right) = \rho_{R^*} \log \left(\frac{R_t^*}{R^*} \right) + \varepsilon_{R^*,t+1}. \quad (37)$$

2.5 Alternative Monetary and Macprudential Frameworks

We start with a specification that removes the price rigidities and financial frictions, which we denote as the “natural” allocation of the model economy. When both frictions are present, we need to characterize the macroeconomic policies implemented to complete the model economy. We assume that the monetary policy instrument is the interbank market rate, R_t^{IB} , and that the macroprudential tool is the time-varying reserve requirement, s_t^{MA} . We set different rules for these instruments as a way to define alternative monetary and macroprudential arrangements.

(i) *Standard Taylor-type rule and constant reserve requirement.*¹²

In this case monetary policy is characterized by the following reaction rule for the interbank rate (in annual terms):

$$\begin{aligned} \log \left(\frac{R_t^{IB}}{1+r} \right) &= \psi_R \log \left(\frac{R_{t-1}^{IB}}{1+r} \right) + (1 - \psi_R) (\psi_\pi \log(1 + \pi_t) \\ &\quad + \psi_y \log(y_t)), \end{aligned}$$

¹²Most IT emerging market countries follow Taylor-type rules for setting policy rates; some of them also react to external variables like the real exchange rate (see Aizenman, Hutchison, and Noy 2011 and Ostry, Ghosh, and Chamon 2012). We focus on simple rules here and elaborate on others in the “robustness” section 5.4.

where we set $\psi_R = 0$, $\psi_\pi = 1.5$, and $\psi_y = 0.5$. The reserve requirement, s_t^{MA} , is constant and equal to its steady-state value, $s_t^{MA} = 0.10$.

- (ii) *Inflation-targeting regime and constant reserve requirement.* In this situation monetary policy is modeled as an implicit contingent rule that achieves a full stabilization of inflation in every period and every state. As in the previous case, the reserve requirement is constant at its steady-state level.
- (iii) *Augmented Taylor-type rule with a countercyclical reaction to credit (entrepreneurs' loan).* In this case, we extend the Taylor-type rule described in (i) to include a countercyclical reaction to fluctuations in entrepreneurs' loan:

$$\log \left(\frac{R_t^{IB}}{1+r} \right) = \psi_R \log \left(\frac{R_{t-1}^{IB}}{1+r} \right) + (1 - \psi_R) (\psi_\pi \log (1 + \pi_t) + \psi_y \log (y_t) + \psi_b \log (b_t)),$$

where we consider $\psi_R = 0$, $\psi_\pi = 1.5$, $\psi_y = 0.5$, and $\psi_b = 0.25$. Again, the reserve requirement is constant at its steady-state level.

- (iv) *Inflation-targeting regime combined with a countercyclical reserve requirement.* As in case (ii), the interbank rate follows an implicit rule that guarantees that inflation is fully stabilized in every period and state. The inflation-targeting regime is combined with a macroprudential rule that adjusts the reserve requirement countercyclically to accommodate domestic financial conditions, as summarized by excess reserves.¹³ This possibility is modeled as follows:

$$\log \left(\frac{s_t^{MA}}{s^{MA}} \right) = -\phi_{xr} \log \left(\frac{xr_t}{xr} \right),$$

where $\phi_{xr} = 10$.

¹³Edwards and Vegh (1997) demonstrate the desirability of using a countercyclical reserve requirement in the context of a fixed-exchange-rate regime; however, they assume that the reserve requirement moves directly with foreign interest rates rather than with domestic financial conditions.

3. Baseline Calibration and Welfare Analysis Methodology

The model is calibrated for a quarterly frequency.¹⁴ Thus, households' discount factor will be set at $\beta = 0.99$ while households' utility per period is specified as

$$u\left(c_t, h_t, \frac{M_t}{P_t}\right) = \ln\left(c_t - \gamma_h \frac{(h_t)^{1+\sigma_L}}{1+\sigma_L}\right) + \frac{a_m}{j} \left(\frac{M_t}{P_t}\right)^j,$$

where $\sigma_L = 1$, γ_h is such that, in the steady state, hours worked corresponds to a third of the available hours for the representative household ($h = 1/3$). The steady-state inflation rate is set at zero ($\pi = 0, \pi^* = 0$), implying that, at the steady state, the (gross) deposit rate is $R^D = 1/\beta = 1.01$, which is approximately 4 percent on an annual basis.

The Calvo parameter is set at $\phi_p = 0.75$, which means that the average duration of not having optimally reset prices is four quarters. For the indexation of prices to past inflation, we choose full indexation with $\chi_p = 1.00$.

The ratio of net exports to GDP is 0.5 percent, which implies a foreign debt to annual GDP of around 12.4 percent. We model the external spread as $\Theta(B_t^*) = (B_t^*/B^*)^\varrho$ and we set a very elastic schedule or foreign supply of funds with $\varrho = 0.001$, similar to the value used by Schmitt-Grohé and Uribe (2003) to produce simulations close to a case with a fully elastic foreign supply of funds. The share of foreign goods in the final goods composite is 30 percent ($\alpha_d = 0.30$), while the elasticity of substitution between home and foreign goods is less than one ($\theta_d = \theta^* = 0.5$).

We assume that investment adjustment costs do not affect the steady-state allocations and $Q/P = 1$. This adjustment cost of investment satisfies $\Delta(1) = \Delta'(1) = 0$ and $\Delta''(1) = 5$, as in Smets and Wouters (2007). We choose a quarterly depreciation rate of capital of 2.5 percent ($\delta = 0.025$). The probability of selling the defaulted capital is set at $\eta_K = 1/4$, which implies that on average

¹⁴The model is calibrated to resemble a prototypical emerging market economy such as the ones in figure 1.

the defaulted capital takes one year to be restructured and become productive again.

The production technology assumes a share of capital around one-third ($\theta_y = 0.36$), and by normalization we set $a = 1$ at the steady state. The reserve requirement at the steady state is $s^{MA} = 0.10$, and assuming $R^{RE} = 1$ we have that $R^{IB} = R^D + s^{MA}/(1 - s^{MA})(R^D - R^{RE}) = 1.0112$, which is equivalent to a steady-state interbank rate of 4.5 percent on an annual basis.

For the financial contract we use three main parameters: (i) an annual default rate of 3 percent; (ii) a leverage ratio of 40 percent ($B/k = 0.4$); and (iii) an average cost of liquidation of $\mu = 0.60$. The default rate is in line with the value proposed by BGG (1999), while the leverage ratio is a midpoint between BGG (1999) and the leverage ratio estimated by Gonzalez-Miranda (2012) for a sample of traded companies in Latin American countries. These parameter values imply a risk premium at the steady state $\rho(\bar{\omega}, \mu, \sigma_\omega) = 1.0234$, a recovery rate,

$$recov_t = \frac{(1 - \mu_t) \int_0^{\bar{\omega}_t} \omega d\Phi(\omega; \sigma_\omega) payn_t k_t}{\Phi(\bar{\omega}_t; \sigma_\omega) [R_{t-1}^{IB} B_{t-1}]},$$

of around 36 percent. This implies a return to capital and a lending rate of around 15 and 7 percent, respectively, in annualized terms. We impose a death rate of entrepreneurs of 1 percent quarterly ($\lambda = 0.01$). With this parameter, the entrepreneurs' debt and deposits, as a percentage of GDP in annual terms, are about 55 percent and 61 percent, respectively.

For the liquidation services, we use $\alpha_{lq} = \alpha_{xr} = 0.3$, which is coherent with the calibration used by Choi and Cook (2012). We normalize the steady-state marginal cost of final goods and excess reserves needs for the liquidation services (f and g) such that the excess reserves corresponds to 0.25 percent of deposits. This normalization implies that excess reserves are around 0.15 percent as a percentage of annual GDP.

We perform a numerical approximation of the equilibrium conditions to solve for the dynamics around the deterministic steady state of the model (see appendix 4 for the full set of equilibrium conditions of the model economy). The simulations are performed with a first-order approximation. However, to compute the welfare

we use a second-order approximation, which allows us to obtain the welfare ranking among alternative policy frameworks (Faia and Monacelli 2007).¹⁵ More precisely, we use a pruned state-space system for the second-order approximation (see Andreasen, Fernández-Villaverde, and Rubio-Ramírez 2013).¹⁶ Although we have households and entrepreneurs, for the computation of welfare only the utility of households matters since entrepreneurs are risk neutral. Also, for the welfare computation we assume that the weight of real money balances in the household's utility is very small, such that $a_m \approx 0$.

We compute welfare as the second-order approximation of the ergodic mean of the discounted value of the utility function of households. Thus, welfare of policy framework i is computed as the second-order approximation of

$$W(i) = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \ln \left(c(i)_t - \gamma_h \frac{(h(i)_t)^{1+\sigma_L}}{1+\sigma_L} \right) \right\}.$$

Then, we compute the cost of policy framework i in terms of consumption such as a λ_i that satisfies

$$W(i) = \frac{1}{1-\beta} \ln \left(\bar{c}(1-\lambda_i) - \gamma_h \frac{(\bar{h})^{1+\sigma_L}}{1+\sigma_L} \right),$$

where $\bar{c}$ and $\bar{h}$ are the steady-state levels of consumption and labor without nominal and financial frictions.

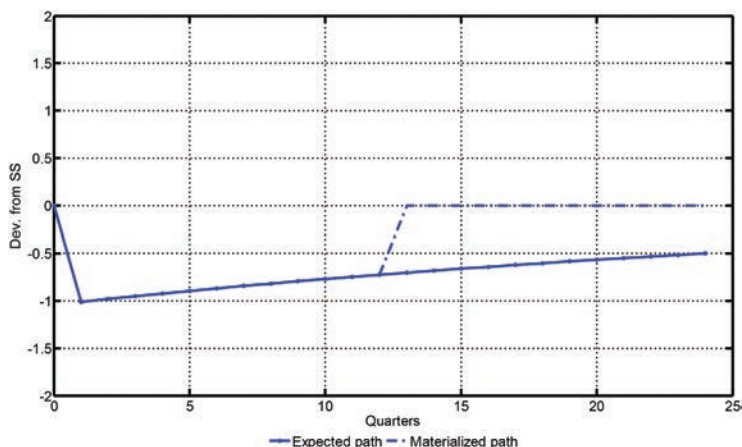
Recall that the process for the foreign interest rate is given by

$$\log \left(\frac{R_{t+1}^*}{R^*} \right) = \rho_{R^*} \log \left(\frac{R_t^*}{R^*} \right) + \varepsilon_{R^*,t+1},$$

¹⁵Ozcan and Unsal (2013) follow a similar strategy to study productivity and financial shocks.

¹⁶It is worth noting that this second-order approximation includes a constant term for the dynamic behavior of each endogenous variable. These constants capture the effects of volatility in the level of each variable implied by each alternative policy regime and conditional on the same distribution of the shocks of the foreign interest rate. Starting from the same deterministic steady state, these constants account for the transitional effect to the ergodic means, which are different across alternative policy regimes (see Faia and Monacelli 2007).

Figure 4. Expected and Materialized Path for the Foreign Interest Rate



where $\varepsilon_{R^*,t+1}$ is an iid shock with mean zero and standard deviation equal to σ_{R^*} . Assuming that the only source of fluctuations is the foreign interest rate, the welfare of each policy regime is computed assuming ρ_{R^*} equal to 0.97 and σ_{R^*} equal to 0.25 percent.

4. Policy Responses to Capital Inflows and Reversals

We consider the responses of the model economy to a transitory reduction in the foreign interest rate, which is initially perceived to be highly persistent. However, after twelve quarters, the foreign interest rate unexpectedly rises to its original level. This situation is associated with large capital inflows and a “sudden stop” in the twelfth quarter. Figure 4 illustrates the path for the foreign interest rate.

We study this specific scenario for a couple of reasons. First, the initial, protracted decline in world interest rates captures the extended period of accommodative monetary policies in advanced countries after Lehman’s bankruptcy. In the model, both the monetary authority and private-sector agents share the initial view that the world rate can be approximated with an AR(1) process with estimated coefficient of ρ_{R^*} close to one, which implies a very persistent

reduction in the foreign interest rate. Second, it is uncertain how the process of “normalization” of monetary policy is going to pan out, especially in the United States. A review of recent tightening episodes (see IMF 2013b) suggests that there are no clear tightening patterns and that long rates (perhaps more relevant for capital flow recipient countries) followed an even less predictable pattern; in the 1994–95 episode, however, long rates spiked right after the beginning of the tightening process. It is in this type of scenario where macroprudential policies are expected to contribute the most.

More precisely, we analyze a situation of an unanticipated shock $\varepsilon_{R*,t} < 0$, which induces a reduction in the foreign interest rate which is perceived to last according to a persistence coefficient $\rho_{R*} = 0.97$.¹⁷ However, after p quarters, the expectation of the low foreign interest rate is reversed unexpectedly to its original level ($\varepsilon_{R*,t+p} = -(\rho_{R*})^{p-1}\varepsilon_{R*,t}$). This scenario is similar to those discussed in the “news” literature (Jaimovich and Rebelo 2009; Christiano et al. 2010) whereby an initial signal of future positive developments (high future productivity there, low foreign rates here) later on turn out to be incorrect.

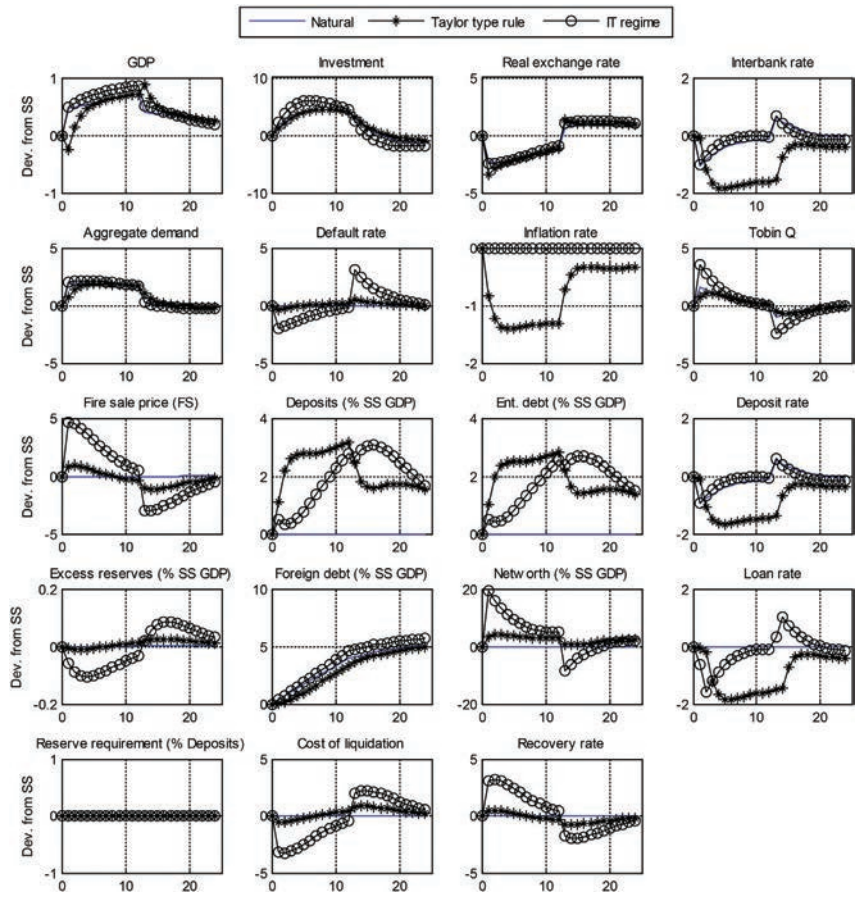
The reduction in world interest rates triggers a sharp increase in aggregate demand, GDP, and asset prices (see figure 5, thin line). The “natural” (interbank) rate in the model without frictions follows the world rate and induces a current account deficit (i.e., an increase in foreign borrowing) and a real exchange rate appreciation. When the world rate unexpectedly increases back to its pre-shock level twelve quarters later, it sets in motion the reverse process, but the intrinsic dynamics of the model deliver only a slowdown in the increase in foreign debt—rather than a “sudden stop” or reversal of flows.

The first policy response we analyze is when the monetary authority follows a “standard” Taylor rule (Taylor 1993).¹⁸ In this

¹⁷This is the estimated coefficient of an autoregressive process of order 1 for the federal funds rate since 2000.

¹⁸In reading the results with our benchmark model with nominal and financial frictions, it is worth keeping in mind the well-known results that with only nominal frictions, IT constitutes an optimal regime (Woodford 2003) and that, likewise, countercyclical macroprudential instruments (akin to Pigouvian taxes) are optimal to manage credit booms and busts (Jeanne and Korinek 2010). In appendix 5, we show these two optimality results for one-friction-only versions of our model when facing the world interest rate shock.

Figure 5. Comparing the Responses under Natural, Taylor-Type Rule, and IT Regime



case, the policy (“interbank”) rate does not fall in the first quarter, leading to a sharp increase in the real interest rate that triggers a deflationary cycle and a stronger real exchange rate appreciation. The policy rate starts falling after the first quarter, even beyond the natural rate, and induces a sharp increase in credit (entrepreneur debt).

The pure inflation-targeting (IT) regime stabilizes inflation but exacerbates fluctuations in aggregate demand and asset prices.

Table 1. Welfare Comparison under Foreign Interest Rate Shocks

Policy Framework	Welfare	Ranking	λ
Standard Taylor-Type Rule	−82.37	2	16.8%
IT Regime	−83.56	4	17.4%
Augmented Taylor-Type Rule	−82.45	3	16.8%
IT Regime and Countercyclical RR	−75.09	1	12.8%

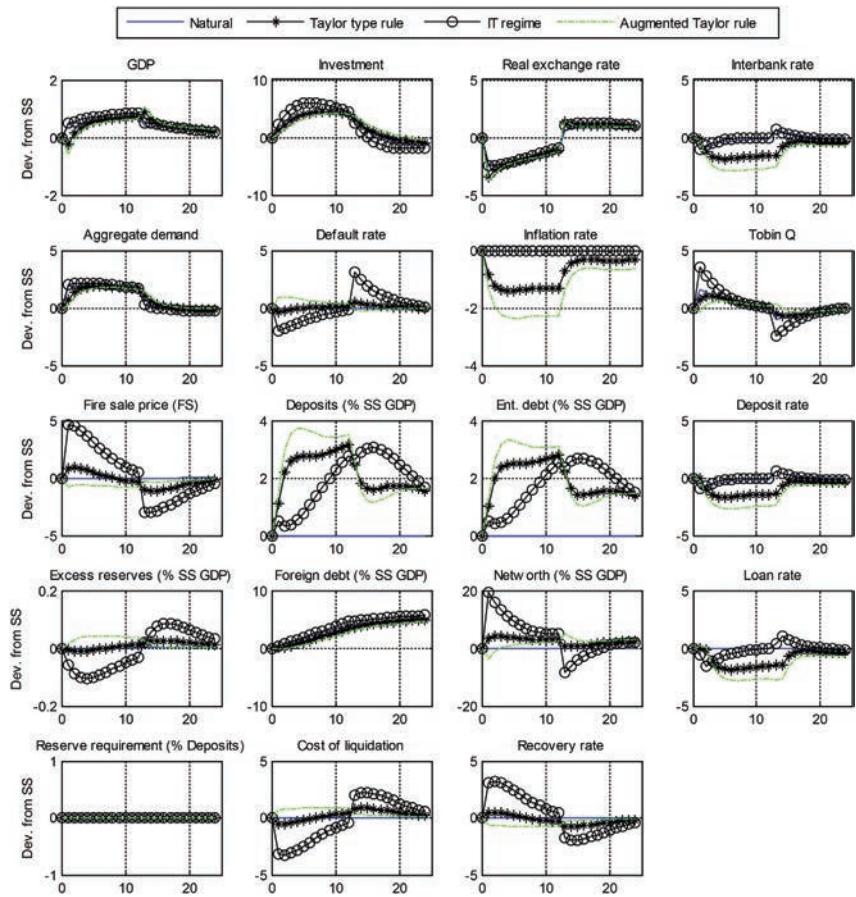
Entrepreneur debt does not increase as much as before, in part because the sharp increase in the price of capital (“Tobin Q” in figure 5) increases net worth, reducing the need for external funds. Associated with the higher asset price volatility are sharper swings in default and recovery rates, as well as a highly procyclical cost of liquidation (in contrast to the constant one in BGG 1999). The procyclicality of the financial sector is also reflected in the more cyclical behavior of excess reserves used to provide liquidity services: they fall in the first three years and are restored when world interest rates go back up thereafter.

As shown in table 1, welfare is higher with the standard Taylor rule than with the IT regime. The IT regime fully neutralizes the nominal friction but induces higher financial volatility and a higher cost of the financial frictions; the Taylor rule neutralizes partly the latter by smoothing the associated GDP fluctuations.

A more direct way to respond to the enhanced financial volatility is to add a term associated with credit growth in the Taylor rule.¹⁹ The results are shown in figure 6. By resisting further the drive to lower interest rates in the first period, this “augmented Taylor rule” (ATR) delivers stronger deflationary pressures. And the further smoothing of asset prices contains the increase in net worth, with the ironic result that credit ends up growing faster than with the standard Taylor rule (TR). As a result, the ATR is dominated in welfare terms by the standard TR (table 1). This result contrasts with the one found in Christiano et al. (2010), where the addition

¹⁹This is akin to “leaning against the wind,” although the expression could be applied more broadly to responses to asset prices and other indicators of financial conditions.

Figure 6. Comparing the Responses under Natural, IT Regime, and Augmented Taylor



of credit growth to the standard Taylor rule improves welfare. The reason for the different result is that the shock in Christiano et al. (2010) is an expected increase in productivity that *raises* the natural interest rate. Here the initial shock *lowers* the natural interest rate, so adding credit growth with a positive coefficient in the Taylor rule moves the economy further away from the natural path. The result is, however, in agreement with Christiano et al. (2010) in the sense that focusing exclusively on goods price inflation can lead to sharp

moves in asset prices, thus making it desirable to move away from strict inflation targeting (that is here dominated by both the TR and ATR in welfare terms, table 1).

An alternative way to respond to both the nominal and financial frictions is to use another, macroprudential instrument: a countercyclical reserve requirement (s_t^{MA}), as defined in regime (iv) in section 2.5.²⁰

Reserve requirements increase substantially in the first two years, from 10 percent of deposits to just above 30 percent at the end of the first year. More importantly, they are reduced to less than the original 10 percent rate after the reversal in world interest rates (as done by several emerging market countries in the aftermath of the Lehman bankruptcy; see figure 1). The combined monetary–macroprudential regime brings all macroeconomic variables closer to their “natural levels” and smoothes the volatility of financial variables (figure 7). In particular, it is much more effective in containing credit growth than the augmented Taylor rule, and delivers clear welfare gains relative to all other regimes (table 1).

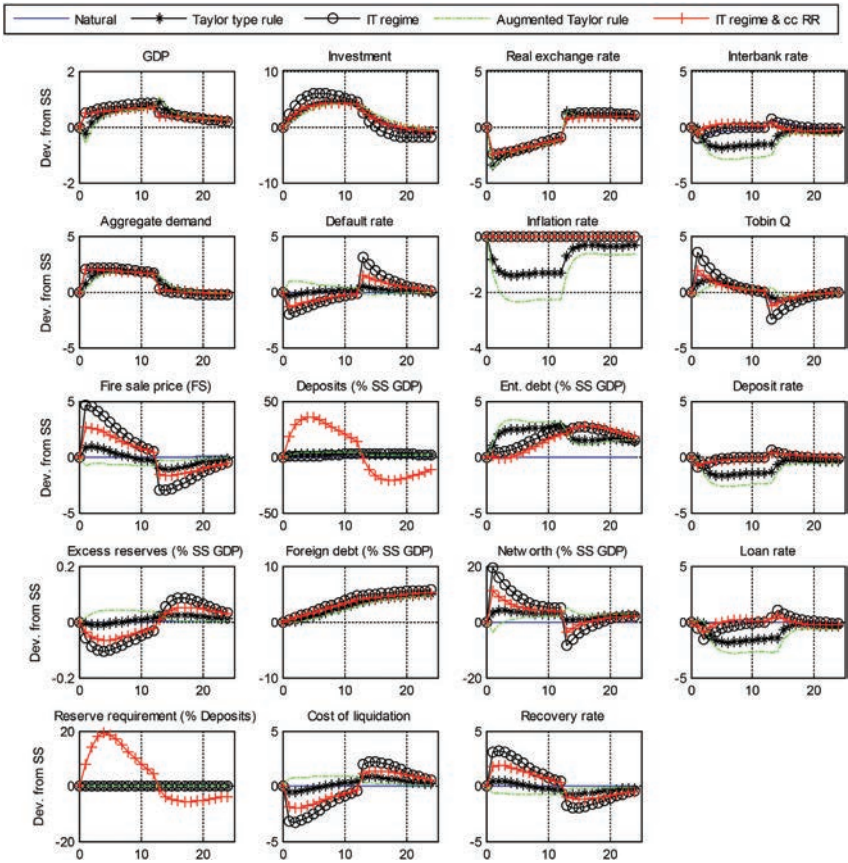
The fact that the use of the macroprudential instrument improves welfare beyond the augmented Taylor rule underscores the drive to expand the macroeconomic policies toolkit (IMF 2013a). Financial frictions abound, and the use of an additional cyclical instrument results in a better management of the two frictions/distortions in the model. We interpret this result as reflecting the Tinbergen principle of “one instrument for each objective” and Mundell’s “principle of effective market classification,” whereby instruments should be paired with the objectives on which they have the most influence (see Beau, Clerc, and Mojon 2012 and Glocker and Towbin 2012).

In this case, the macroprudential instrument mitigates the financial friction while the monetary policy rate neutralizes the nominal friction.

It is also important to note that the use of the macroprudential instrument has implications for the monetary policy instrument. In

²⁰Bianchi (2011) demonstrates that, for a very generic bank balance sheet, capital and reserve requirements have similar effects (see also Benigno 2013). Agénor, Alper, and Pereira da Silva (2013) study interactions between interest rate rules and a Basel III-type countercyclical capital regulatory rule in the management of housing demand shocks.

Figure 7. Comparing the Responses under Natural, IT Regime, Augmented Taylor, and IT Regime Combined with Countercyclical Reserve Requirement



particular, while the “natural” interest rate falls in the early part of the exercise, the policy rate falls only marginally but is driven above its original level after one year, to accommodate the impact of the increased reserve requirement. As noted in IMF (2013a), “the conduct of both policies will need to take into account the effects they have on each other’s main objectives”; we would add that this exercise demonstrates also the need to coordinate both policy instruments, especially when dealing with swings in capital flows.

Table 2. Welfare Comparison with Foreign Borrowing

Policy Framework	Welfare	Ranking	λ
Standard Taylor-Type Rule	−83.48	2	17.3%
IT Regime	−84.57	4	17.9%
Augmented Taylor-Type Rule	−83.50	3	17.3%
IT Regime and Countercyclical RR	−69.92	1	9.7%

5. Robustness

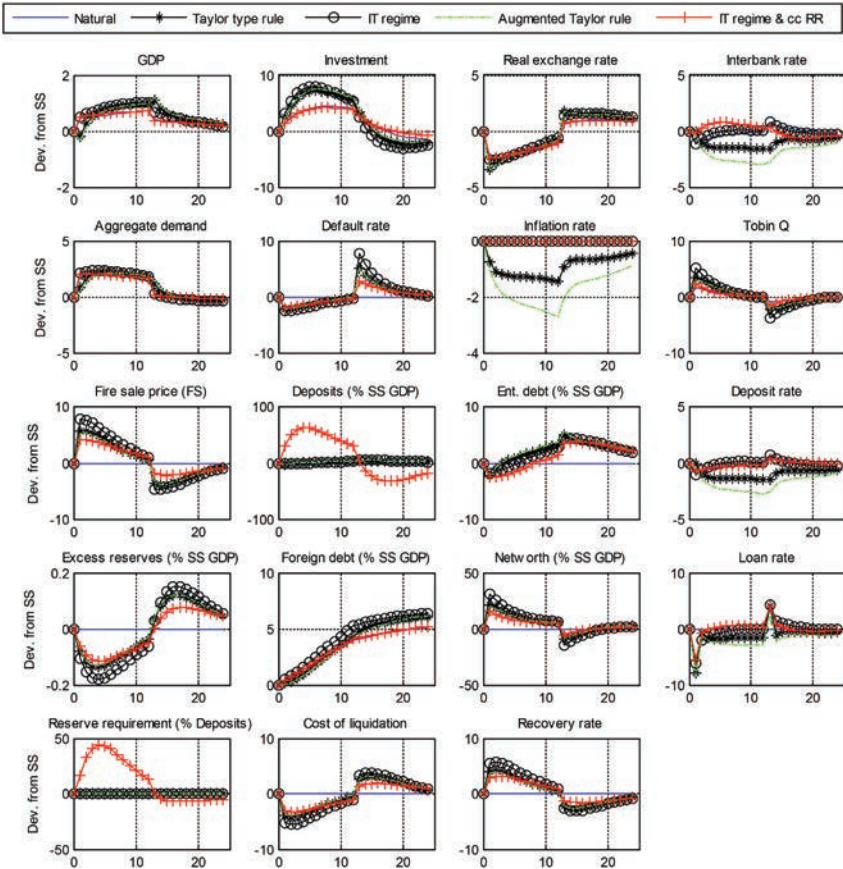
In this section, we analyze the robustness of the results discussed in the previous section. In particular, we study ways in which both the financial and the nominal distortions could be enhanced and how those changes might alter the policy rankings. We also explore a calibration where liquidity services represent a larger share of financial services, and study a popular family of rules for emerging market economies—that adds the exchange rate as a third argument. We conclude with an analysis of standard macro shocks in our model economy.

5.1 Foreign Borrowing and Dollarization

So far the only agents that hold foreign liabilities are the households. In this section, we assume that both entrepreneurs and lending intermediaries have direct access to external funding in world markets. For simplicity, we assume that these levels of borrowing are constant, thus capturing only the valuation or “balance sheet” effects associated with such borrowing (see appendix 6 for details). We also allow, in a separate exercise, for dollarization of credit, i.e., half of the entrepreneurs’ borrowing can be done in dollar-indexed instruments (appendix 7).

The case where entrepreneurs and lending intermediaries have direct access to external funding yields the same ranking of policies as before (table 2). With dollarized liabilities, the initial real exchange rate appreciation magnifies the increase in entrepreneurs’ net worth and requires less borrowing—indeed there is an initial reduction in credit. This case exemplifies an economy that is more integrated financially to the rest of the world, hence there is more

Figure 8. The Role of Partial Dollarization in the Entrepreneurs' Loan



transmission of the world interest rate shock and lending interest rates fall substantially in the early periods.

The case with partial dollarization of entrepreneurs' borrowing exacerbates the financial distortion, leading to more financial volatility (or instability) and to a change in the ranking of policies. As can be seen in figure 8, aggregate demand, GDP, the real exchange rate, and financial variables fluctuate much more than before (with the default rate spiking to almost 10 percent and net worth increasing by more than 20 percent of GDP after the initial shock). As shown

Table 3. Welfare Comparison with Partial Dollarization in Entrepreneurs’ Loans

Policy Framework	Welfare	Ranking	λ
Standard Taylor-Type Rule	−84.74	2	18.0%
IT Regime	−85.17	3	18.2%
Augmented Taylor-Type Rule	−85.33	4	18.3%
IT Regime and Countercyclical RR	−56.07	1	0.9%

in table 3, the IT regime with macroprudential policies continues to dominate all other monetary policy “only” regimes, but now the IT regime dominates the augmented Taylor rule.

5.2 *Wage Rigidities*

To model wage rigidities in a simple manner, we follow closely Blanchard and Galí (2007), assuming that only a fraction $1 - \phi_w$ of households can demand a real wage increase consistent with labor market conditions as summarized by equation (4). The rest of the households (a fraction ϕ_w) adjust nominal wages according to inflation. Hence, the aggregate nominal wage inflation is given by

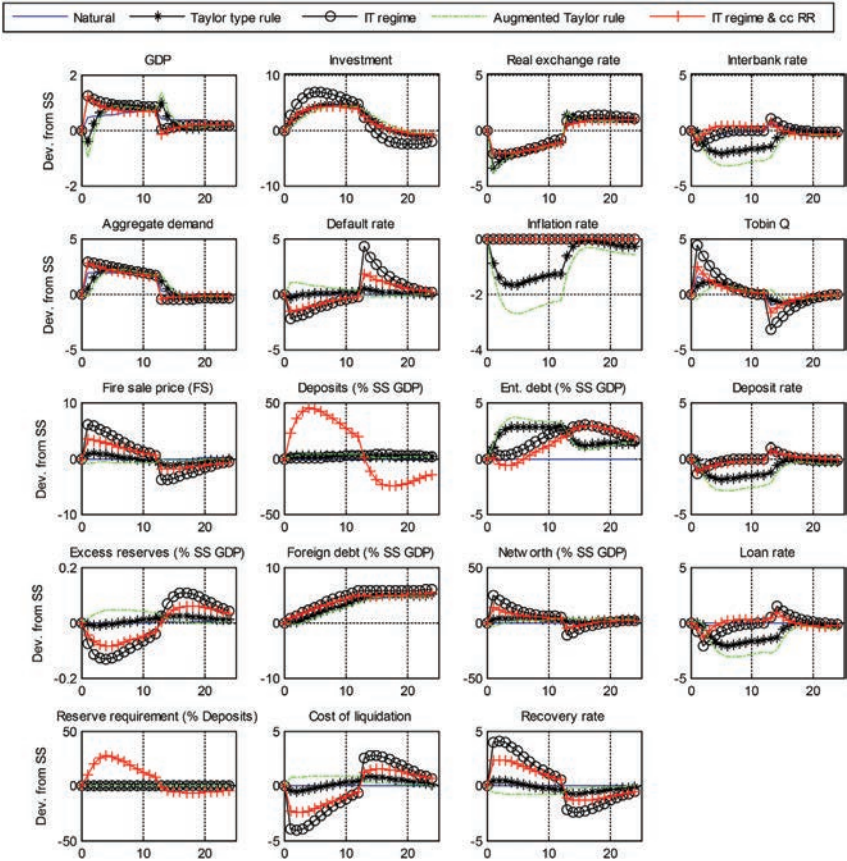
$$\begin{aligned} \log (1 + \pi_t^w) = & (1 - \phi_w) \left(\log \left(-\frac{u_{h,t}}{u_{c,t}} \right) - \log \left(\frac{W_{t-1}}{P_{t-1}} \right) \right. \\ & \left. + \log (1 + \pi_t) \right) + \phi_w \log (1 + \pi_t), \end{aligned} \tag{38}$$

and the evolution of the aggregate real wage is given by

$$\begin{aligned} \log \left(\frac{W_t}{P_t} \right) - \log \left(\frac{W_{t-1}}{P_{t-1}} \right) = & \log (1 + \pi_t^w) - \log (1 + \pi_t) \\ = & (1 - \phi_w) \left(\log \left(-\frac{u_{h,t}}{u_{c,t}} \right) - \log \left(\frac{W_{t-1}}{P_{t-1}} \right) \right). \end{aligned} \tag{39}$$

This specification is meant to capture the notion that real wages may respond with inertia to labor market conditions and that inflation fluctuations can be a source of dynamics of real wages. For the model

Figure 9. The Role of Wage Rigidities



simulations under wage rigidities, we use $\phi_w = 0.875$, which corresponds to a case where households set their nominal wages every eight quarters.

The addition of this nominal rigidity further exacerbates asset price and default/recovery fluctuations (figure 9), as well as exchange rate movements. And the welfare gains of using the countercyclical reserve requirement are even larger than with only price rigidities—reaching 7 percent of steady-state consumption, compared with 4 percent in the benchmark case (table 4).

Table 4. Welfare Comparison with Wage Rigidities

Policy Framework	Welfare	Ranking	λ
Standard Taylor-Type Rule	−82.19	2	16.7%
IT Regime	−83.69	4	17.6%
Augmented Taylor-Type Rule	−82.30	3	16.7%
IT Regime and Countercyclical RR	−70.40	1	10.0%

5.3 Larger “Excess Reserves”

As noted in section 2.3, “excess reserves” are liquid assets that facilitate the purchase of defaulted or distressed capital. Hence, they may encompass a broader set of assets than the strict definition of excess reserves in traditional banks.²¹ High-quality liquid assets, such as those included in the numerator of the *liquid coverage ratio* (Basel Committee on Banking Supervision 2013) would be closer to the spirit/nature of the assets used by our liquidity intermediary to buy defaulted/distressed assets.

In this section, we explore the robustness of our results to a larger size of what we call “excess reserves.” Our baseline calibration assumes that 0.25 percent of deposits are kept as excess reserves, and this could be considered a small fraction if one recognizes that banks hold around 10 percent of assets in trading-related assets (King 2010) and around 12 percent in government securities.²² However, the simplicity of our financial intermediaries’ balance sheet constrains how much we can increase “excess reserves” without deviating from other stylized facts we adopted for our calibration. Thus, we assume in this section that “excess reserves” are 1.5 percent of

²¹Gray (2011) noted that reserves are used to smooth settlement of transactions and respond to unexpected deposit withdrawals. When reserves are kept for prudential purposes, they could be held not just with vault cash and deposits at the central bank but also with liquid treasury securities.

²²The four countries in figure 1 hold on average 12.4 percent of total assets in government securities, but there is wide variation across countries; for Brazil and Turkey the figure is around 20–24 percent, while for Colombia and Peru it is around 2–4 percent (averages for the period 1998–2012). It is worth noting that this holding of government securities has been reduced in Brazil since 2006, reaching around 13 percent of total assets in 2012.

deposits (six times bigger than in the baseline).²³ Since the amount of “excess reserves” is related to the resources demanded for liquidation services, we need to increase the average default rate (and reduce the average recovery rate) to induce a higher proportion of “excess reserves.” We select a quarterly default rate of 4 percent and an average value of μ such that the recovery rate is around 31 percent on average.²⁴ We also modify the curvature of the liquidation technology setting $\alpha_{lq} = \alpha_{xr} = 0.15$. The remaining parameters of the liquidation services technology remain the same as the baseline calibration.²⁵

The alternative calibration gives a higher role to financial frictions, resulting in more volatile asset prices, more volatile default and recovery rates, and a loan rate that is more procyclical. Interestingly, an inflation-targeting regime may not require a fall in the monetary policy rate in the boom phase of the cycle, in contrast to the responses in the baseline calibration—though this response of monetary policy is not effective in stabilizing GDP, aggregate demand, or the financial variables (figure 10). Thus, a more procyclical financial sector constrains how loose monetary policy can be in response to a reduction in the world interest rate. In terms of welfare, the results still show the superiority of a policy mix that uses simultaneously an inflationtargeting regime with a countercyclical reserve requirement, though the welfare gains are smaller (table 5). More important, using the reserve requirement requires a monetary policy rate that increases in the boom phase and is reduced in the downturn. This behavior accommodates the countercyclical use of reserve requirements and highlights a bigger deviation of the monetary policy rate from the natural rate.

²³In the case of Peru, the sum of government securities and cash held by commercial banks in the period 2003–12 was equivalent to 25 percent of deposits, while the effective reserve requirement was about 23.5 percent. In the same period, excess reserves were 0.35 percent of deposits.

²⁴This higher default rate could be rationalized as the “distress” rate obtained in estimates from credit default swap rates (see Hull, Predescu, and White 2004).

²⁵This calibration implies the following for steady-state rates: $R^K = 38.5\% > R^L = 15.8\% > R^{IB} = 4.5\% > R^D = 4\%$.

Figure 10. The Role of Higher Excess Reserves

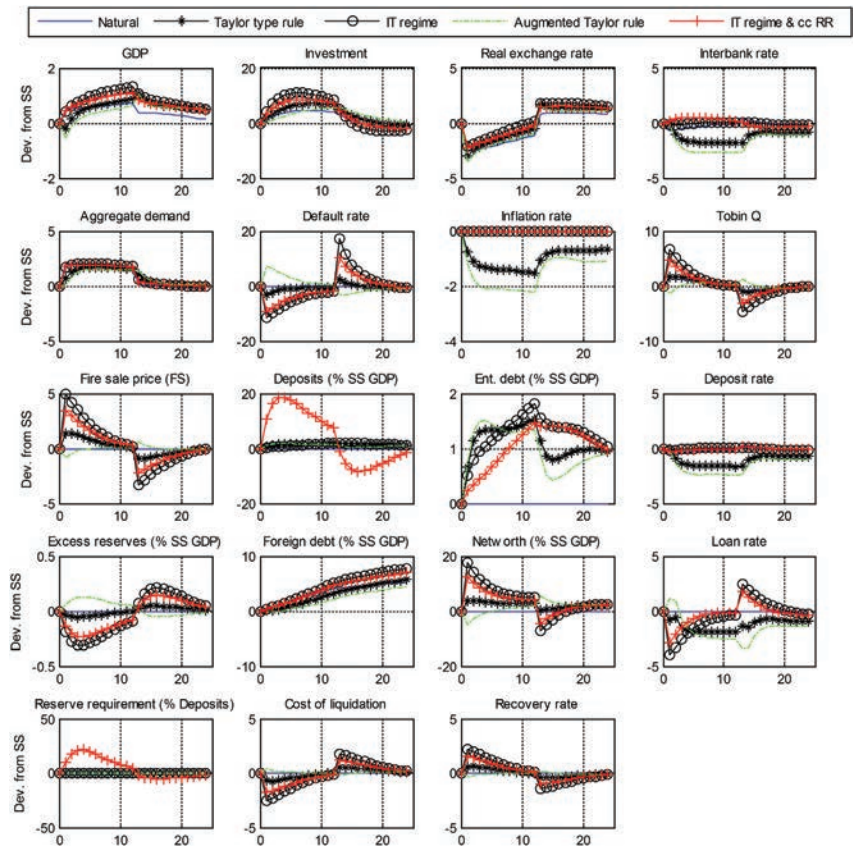


Table 5. Welfare Comparison with Higher Excess Reserves

Policy Framework	Welfare	Ranking	λ
Standard Taylor-Type Rule	−89.72	2	20.5%
IT Regime	−92.59	4	21.9%
Augmented Taylor-Type Rule	−90.09	3	20.7%
IT Regime and Countercyclical RR	−86.08	1	18.7%

5.4 Taylor Rule with “Fear of Floating”

Several emerging economies follow Taylor-type rules that also react to external variables—in particular, real exchange rates (see Aizenman, Hutchison, and Noy 2011; Ostry, Ghosh, and Chamon 2012).²⁶ This behavior of central banks has been called “fear of floating,” as they try to smooth real exchange rate fluctuations to protect dollarized balance sheets from the amplification effects demonstrated in section 5.2. Hence, empirical estimates of the Taylor rules for emerging economies postulate a rule as

$$\begin{aligned} \log \left(\frac{R_t^{IB}}{1+r} \right) = & \psi_R \log \left(\frac{R_{t-1}^{IB}}{1+r} \right) + (1 - \psi_R) (\psi_\pi \log (1 + \pi_t) \\ & + \psi_y \log (y_t) + \psi_{rer} \log (rer_t)), \end{aligned}$$

where $\psi_{rer} > 0$. In this way, the monetary policy rate is lower than what would be dictated by the standard Taylor rule when the real exchange rate is appreciating. Using our benchmark model, we study the welfare metrics, adding this alternative rule. To our benchmark calibration, we add $\psi_{rer} > 0.1$, which is consistent with the estimates by Ostry, Ghosh, and Chamon (2012). The results are presented in table 6. It is interesting to note that the IT regime with the counter-cyclical macroprudential instrument continues to deliver the highest welfare ranking. It is also interesting that even with the financial friction, a simple Taylor rule dominates the ones that react to credit growth or the real exchange rate.

5.5 Preference and Technology Shocks

Even though the main goal of the paper is to study policy responses to world interest rate shocks (and the associated fluctuations in capital flows to emerging markets), in this section we study the behavior of our model to standard preference (demand) and technology (supply) shocks. We extend the model to include a preference shock. Hence, the intertemporal preferences of the households are now characterized by

²⁶Both papers find that in fourteen to sixteen inflation-targeting emerging markets, real exchange rates are statistically significant in Taylor rules estimated with panel regressions.

Table 6. Welfare Comparison under Fear of Floating

Policy Framework	Welfare	Ranking	λ
Standard Taylor-Type Rule	-82.37	2	16.8%
IT Regime	-83.56	4	17.4%
Augmented Taylor-Type Rule	-82.45	3	16.8%
IT Regime and Countercyclical RR	-75.09	1	12.8%
Taylor Rule with Fear of Floating	-85.77	5	18.5%

Table 7. Welfare Comparison under Demand Shocks

Policy Framework	Welfare	Ranking	λ
Standard Taylor-Type Rule	-78.22	4	14.5%
IT Regime	-77.94	2	14.4%
Augmented Taylor-Type Rule	-78.21	3	14.5%
IT Regime and Countercyclical RR	-75.83	1	13.2%

$$U_t = E_t \left[\sum_{i=0}^{\infty} \beta^i \varphi_{g,t} u \left(c_t, h_t, \frac{M_t}{P_t} \right) \right],$$

where $\varphi_{g,t}$ is an exogenous preference shock that evolves as

$$\log (\varphi_{g,t+1}) = \rho_{\varphi} \log (\varphi_{g,t}) + \varepsilon_{\varphi,t+1}.$$

Here $\varepsilon_{\varphi,t+1}$ is an iid innovation with mean zero and standard deviation equal to σ_{φ} . Table 7 shows the welfare computation, assuming that the only source of fluctuations are demand shocks with $\rho_{\varphi} = 0.80$ and σ_{φ} equal to 5 percent. We can see that the IT regime with countercyclical reserve requirements continues to be the optimal choice, even for this purely “macro” shock.

We consider next only technology shocks. Recall that the aggregate production of domestic goods is given by

$$y_t = a_t (k_t)^{\theta_y} (h_t)^{1-\theta_y},$$

Table 8. Welfare Comparison under Productivity Shocks

Policy Framework	Welfare	Ranking	λ
Standard Taylor-Type Rule	−86.37	2	18.8%
IT Regime	−91.27	4	21.3%
Augmented Taylor-Type Rule	−84.19	1	17.7%
IT Regime and Countercyclical RR	−88.71	3	20.0%

and we thus model productivity fluctuations as

$$\log(a_{t+1}) = \rho_a \log(a_t) + \varepsilon_{a,t+1},$$

where $\varepsilon_{a,t+1}$ is an iid innovation with mean zero and standard deviation equal to σ_a . Having productivity shocks as the only source of fluctuations with $\rho_a = 0.97$ and $\sigma_a = 3$ percent, table 8 presents the welfare computation.

It is well known that (positive) technology or supply shocks deliver a difficult tradeoff of expanding activity and lower inflation that is best managed under our parameterization by a standard Taylor rule. Nevertheless, in the face of these shocks, the countercyclical reserve requirement still improves welfare relative to a pure IT regime.²⁷

6. Conclusions

The use of macroprudential policy instruments has become increasingly popular in the aftermath of the 2007–09 financial crisis. In this paper we have shown that the use of cyclical macroprudential policies increases welfare, especially in the context of an inflation-targeting regime. We obtain our result in a model with a fairly general but microfounded financial system that provides credit and liquidity services. The dominance of a regime that uses monetary policy to mitigate a nominal friction and a countercyclical reserve

²⁷This is consistent with results in Christiano et al. (2010) and in Gambacorta and Signoretti (2014) that show that leaning against the wind improves welfare when the economy is subject to productivity shocks, although they do it with a very different financial intermediary structure than the one in this paper.

requirement to mitigate the financial friction is robust to institutional features such as dollarization of liabilities (that tend to exacerbate financial frictions), wage rigidities (that increase nominal frictions), and alternative calibrations of the financial system and/or policy rules.

The paper also shows the importance of coordinating the use of the monetary policy rate to the countercyclical macroprudential policy instrument. When both instruments are used, the monetary policy rate may deviate substantially from the rate associated with a pure IT regime (and that of the economy's natural rate that follows closely the world interest rate).

Our results also point to the potential perils of “leaning against the wind” of financial instability regardless of the nature of the shock hitting the economy. IMF (2012) suggests that when macroprudential policies operate less than perfectly, monetary policy may lean against the credit cycle—but also provides a number of cases and conditions under which this may not be optimal, especially in the open economy. In this paper, we have shown that when world interest rates are reduced dramatically, as in the current juncture, responding with the policy rate to increases in credit growth may not always be the right policy response.

Our results are robust to a number of modifications that exacerbate either friction as well as to different specifications of the Taylor rule. In particular, we show how dollarized liabilities—a hallmark of many emerging markets—exacerbate financial frictions and make the welfare gains of combining IT with a countercyclical macroprudential instrument even larger. They also show how a more procyclical financial system—also a feature of emerging markets—constrains how loose domestic monetary policy can be in response to loose global monetary conditions.

Appendix 1. The Lending Problem

The lending problem results from the following maximization of the entrepreneurs' payoff:

$$\max_{k_{t+1}, \bar{\omega}_{t+1}} E_t \{ \text{payn}_{t+1} k_{t+1} f(\bar{\omega}_{t+1}, \sigma_\omega) \} \quad (40)$$

$$s.t. \quad \text{payn}_{t+1} k_{t+1} g(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega) \geq R_t^{IB} B_t = R_t^{IB} (Q_t k_{t+1} - \text{netn}_t)$$

for all states in $t + 1$, where $B_t = Q_t k_{t+1} - \text{net}n_t$ is the domestic loan to the entrepreneurs with net worth $\text{net}n_t$.

The first-order conditions with respect to k_{t+1} and $\bar{\omega}_{t+1}$ for this problem are

$$E_t \left\{ \begin{array}{c} \text{pay}n_{t+1} f(\bar{\omega}_{t+1}, \sigma_\omega) \\ + \varphi_{t+1} (\text{pay}n_{t+1} g(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega) - Q_t R_t^{IB}) \end{array} \right\} = 0 \quad (41)$$

$$\text{pay}n_{t+1} k_{t+1} f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_\omega) + \varphi_{t+1} \text{pay}n_{t+1} k_{t+1} g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega) = 0, \quad (42)$$

where φ_{t+1} is the Lagrange multiplier in condition (40). Combining (41) and (42), we obtain

$$\begin{aligned} & Q_t E_t \left\{ R_t^{IB} \frac{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_\omega)}{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \right\} \\ &= E_t \left\{ \frac{\text{pay}n_{t+1}}{\rho(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \frac{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_\omega)}{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \right\}, \end{aligned} \quad (43)$$

where $\rho(\cdot)$ is a risk premium defined as

$$\rho(\bar{\omega}_t, \mu_t, \sigma_\omega) = \left[g(\bar{\omega}_t, \mu_t, \sigma_\omega) - f(\bar{\omega}_t, \sigma_\omega) \frac{g_{\bar{\omega}}(\bar{\omega}_t, \mu_t, \sigma_\omega)}{f_{\bar{\omega}}(\bar{\omega}_t, \sigma_\omega)} \right]^{-1}. \quad (44)$$

To express in real terms, we can define $\text{pay}r_t = \text{pay}n_t/P_t$ and $qr_t = Q_t/P_t$ and rewrite (43) as

$$\begin{aligned} & qr_t E_t \left\{ R_t^{IB} \frac{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_\omega)}{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \right\} \\ &= E_t \left\{ (1 + \pi_{t+1}) \frac{\text{pay}r_{t+1}}{\rho(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \frac{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_\omega)}{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \right\}, \end{aligned} \quad (45)$$

where $1 + \pi_{t+1} = P_{t+1}/P_t$. Similarly, defining entrepreneurs' debt and net worth in real terms ($b_t = B_t/P_t$ and $\text{net}r_t = \text{net}n_t/P_t$), we can have the following expressions for the recovery rate, net worth evolution, and entrepreneurs' consumption:

$$\text{recov}_t = \frac{(1 - \mu_t) \int_0^{\bar{\omega}_t} \omega d\Phi(\omega; \sigma_\omega) \text{pay}r_t k_t (1 + \pi_t)}{\Phi(\bar{\omega}_t; \sigma_\omega) [R_{t-1}^{IB} b_{t-1}]} \quad (46)$$

$$\text{net}r_t = (1 - \lambda) f(\bar{\omega}_t, \sigma_\omega) \text{pay}r_t k_t + \tau_E \quad (47)$$

$$c_{K,t} = \lambda f(\bar{\omega}_t, \sigma_\omega) \text{pay}r_t k_t. \quad (48)$$

Appendix 2. The Problem of Liquidity Intermediaries

This appendix presents the liquidity intermediaries problem in a dynamic form, a slightly more general presentation than in the text. Since the defaulted capital held by the liquidity intermediary is a state variable, the full optimization problem can be written in a recursive manner. Let $L(k_{D,t})$ denote the present discounted benefits of having a stock of defaulted capital equal to $k_{D,t}$. This value can be expressed in a recursive form as follows:

$$L(k_{D,t}) = \max_{n_t, s_t, (\frac{D_t}{P_t})} \left\{ \eta_K q_t k_{D,t} + [(1 - s_t) R_t^{IB} + s_t^{MA} R_t^{RE} - R_t^D] \right. \\ \left. \times \frac{D_t}{P_t} \frac{P_t}{R_t^D} - P_t n_t + E_t \left[s d_{t,t+1} L(k_{D,t+1}) \frac{P_t}{P_{t+1}} \right] \right\} \\ s.t. \quad k_{D,t+1} = (1 - \eta_K) (1 - \delta) k_{D,t} + k_{D,t+1}^{new} \quad (49)$$

$$l q_t = \nu k_{D,t} = Z(n_t)^{1-\alpha_{lq}} \quad (50)$$

$$l q_t = \nu k_{D,t} = Z_{xr}(x r_t)^{1-\alpha_{xr}} \quad (51)$$

$$x r_t = (s_t - s_t^{MA}) \frac{D_t}{P_t}, \quad (52)$$

where $s d_{t,t+1}$ is the stochastic discount factor between period t and $t + 1$. The current benefits of the liquidity intermediaries include the sale of the defaulted capital, which occurs with probability η_K at period t . From the law of large numbers, a fraction η_K of the stock of defaulted capital is sold each period. The Lagrangian of the maximization problem in the right-hand side is

$$\mathcal{L} = \left\{ \eta_K q_t k_{D,t} + [(1 - s_t) R_t^{IB} + s_t^{MA} R_t^{RE} - R_t^D] \frac{D_t}{P_t} \frac{P_t}{R_t^D} - P_t n_t \right\} \\ + f_t \left(Z(n_t)^{1-\alpha_{lq}} - \nu k_{D,t} \right) \\ + g_t \left(Z_{xr} \left((s_t - s_t^{MA}) \frac{D_t}{P_t} \right)^{1-\alpha_{xr}} - \nu k_{D,t} \right) \\ + E_t \left[s d_{t,t+1} L((1 - \eta_K) (1 - \delta) k_{D,t} + k_{D,t+1}^{new}) \frac{P_t}{P_{t+1}} \right],$$

where f_t and g_t are the Lagrange multipliers in constraints (50) and (51), respectively. These Lagrange multipliers can be interpreted as the marginal cost of providing liquidation services from final goods and excess reserves. The first-order conditions for n_t , s_t , and $\frac{D_t}{P_t}$ are

$$n_t : -P_t + f_t \frac{(1 - \alpha_{lq})lq_t}{n_t} = 0 \Rightarrow \frac{f_t}{P_t} = \frac{n_t}{(1 - \alpha_{lq})lq_t} \quad (53)$$

$$s_t : -\frac{R_t^{IB}}{R_t^D}P_t + g_t \frac{(1 - \alpha_{xr})lq_t}{xr_t} = 0 \Rightarrow \frac{R_t^{IB}}{R_t^D} = \frac{g_t}{P_t} \frac{(1 - \alpha_{xr})lq_t}{xr_t} \quad (54)$$

$$\begin{aligned} \left(\frac{D_t}{P_t}\right) : & \frac{[(1 - s_t) R_t^{IB} + s_t^{MA} R_t^{RE} - R_t^D]}{R_t^D} P_t \\ & + g_t \frac{(1 - \alpha_{xr})lq_t}{xr_t} (s_t - s_t^{MA}) = 0 \\ \Rightarrow & \frac{[R_t^D - (1 - s_t) R_t^{IB} - s_t^{MA} R_t^{RE}]}{R_t^D} \\ = & \frac{g_t}{P_t} \frac{(1 - \alpha_{xr})lq_t}{xr_t} (s_t - s_t^{MA}). \end{aligned} \quad (55)$$

To complete the characterization of the solution of the dynamic problem, the envelope condition for the recursive problem is

$$\begin{aligned} L'(k_{D,t}) = & \eta_K q_t - \nu (f_t + g_t) + (1 - \eta_K)(1 - \delta) \\ & \times E_t \left[s_{d,t,t+1} L'(k_{D,t+1}) \frac{P_t}{P_{t+1}} \right]. \end{aligned} \quad (56)$$

Defining the presented discounted value of one unit of more defaulted capital as the fire sales ($L'(k_{D,t}) = FS_t$), (56) can be expressed as

$$\frac{FS_t}{P_t} = \eta_K \frac{q_t}{P_t} - \nu \left(\frac{f_t}{P_t} + \frac{g_t}{P_t} \right) + (1 - \eta_K)(1 - \delta) E_t \left[s_{d,t,t+1} \frac{FS_{t+1}}{P_{t+1}} \right]. \quad (57)$$

Appendix 3. Price Rigidities, the Phillips Curve, and Aggregation of Final Goods Demand

There is one final good produced using the intermediate composite goods:

$$da_t = \left(\int_0^1 (da_{i,t})^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}, \quad (58)$$

where ϵ is the elasticity of substitution across the composite intermediate goods and da_t is total domestic demand. The final good market is perfectly competitive, and the demand for each intermediate composite good i is given by

$$da_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\epsilon} da_t \quad \text{for all } i, \quad (59)$$

where $P_{i,t}$ is the price of the intermediate composite good i . The aggregate price level of domestic demand is then

$$P_t = \left(\int_0^1 (P_{i,t})^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}. \quad (60)$$

Each intermediate composite producer has the same technology:

$$da_{i,t} = \left[(1 - \alpha_d)^{1/\theta_d} (y_{i,t})^{1-1/\theta_d} + (\alpha_d)^{1/\theta_d} (y_{f,i,t})^{1-1/\theta_d} \right]^{\frac{\theta_d}{\theta_d-1}}, \quad (61)$$

where $y_{i,t}$ and $y_{f,i,t}$ are, respectively, the amount of domestic and foreign goods used by the intermediate composite producer i . The cost minimization implies

$$\frac{y_{i,t}}{y_{f,i,t}} = \frac{(1 - \alpha_d)}{\alpha_d} \left(\frac{rer_t}{P_{y,t}/P_t} \right)^{\theta_d}, \quad (62)$$

and the marginal cost (expressed in real terms) is

$$mgcr_t = \frac{mgc_t}{P_t} = \left[(1 - \alpha_d) \left(\frac{P_{y,t}}{P_t} \right)^{1-\theta_d} + (\alpha_d) \left(\frac{e_t P_t^*}{P_t} \right)^{1-\theta_d} \right]^{\frac{1}{1-\theta_d}}, \quad (63)$$

which is the same for all intermediate goods producers, because they face the same prices of domestic and foreign goods and their technology is constant return to scale. For the same reason, we can obtain

$$\frac{\int_0^1 y_{i,t} di}{\int_0^1 y_{f,i,t} di} = \frac{y_t - x}{y_{f,t}} = \frac{(1 - \alpha_d)}{\alpha_d} \left(\frac{rer_t}{P_{y,t}/P_t} \right)^{\theta_d}, \quad (64)$$

where we have used the fact that total demand for domestic goods is composed by the demand of intermediate composite producers and exports, x_t . The intermediate composite good producers set prices following Calvo's (1983) mechanism of price adjustment. In each period, a fraction $1 - \phi_p$ of the producers can change optimally their prices. All other producers can only index their prices to past inflation with a weight χ_p . Thus, the problem for the intermediate composite producers i is the following:

$$\begin{aligned} \max_{P_{i,t}} E_t \left\{ \sum_{j=0}^{\infty} sd_{t,t+j} (\phi_p)^j \left(\frac{P_{i,t} \left(\frac{P_{t+j-1}}{P_{t-1}} \right)^{\chi_p}}{P_{t+j}} - mgr_{t+j} \right) da_{i,t+j} \right\} \\ s.t. da_{i,t+j} = \left(\frac{P_{i,t} \left(\frac{P_{t+j-1}}{P_{t-1}} \right)^{\chi_p}}{P_{t+j}} \right)^{-\epsilon} da_{t+j}. \end{aligned}$$

The first-order condition of this problem is

$$\begin{aligned} P_{i,t} (\epsilon - 1) E_t \left\{ \sum_{j=0}^{\infty} sd_{t,t+j} (\phi_p)^j \left(\frac{\left(\frac{P_{t+j-1}}{P_{t-1}} \right)^{\chi_p}}{P_{t+j}} \right)^{-\epsilon} da_{t+j} \right\} \\ = \epsilon E_t \left\{ \sum_{j=0}^{\infty} sd_{t,t+j} (\phi_p)^j mgr_{t+j} da_{t+j} \right\}. \end{aligned} \quad (65)$$

Defining the following expressions in recursive manner,

$$\Omega_{1,t} = mgr_t + \beta \phi_p E_t \left\{ \left(\frac{(1 + \pi_t)^{\chi_p}}{(1 + \pi_{t+1})} \right)^{-\epsilon} \frac{da_{t+1}}{da_t} \frac{u_{c,t+1}}{u_{c,t+1}} \Omega_{1,t+1} \right\} \quad (66)$$

$$\Omega_{2,t} = \frac{P_{i,t}}{P_t} + \beta \phi_p E_t \left\{ \left(\frac{(1 + \pi_t)^{\chi_p}}{(1 + \pi_{t+1})} \right)^{1-\epsilon} \left(\frac{P_{i,t}/P_t}{P_{i,t+1}/P_{t+1}} \right) \times \frac{da_{t+1}}{da_t} \frac{u_{c,t+1}}{u_{c,t+1}} \Omega_{2,t+1} \right\}, \quad (67)$$

the optimal condition for price $P_{i,t}$ (65) can be written as

$$(\epsilon - 1) \Omega_{2,t} = \epsilon \Omega_{1,t}. \quad (68)$$

Using Calvo's pricing mechanism, we can express the price-level aggregation as

$$1 = \phi_p \left(\frac{(1 + \pi_{t-1})^{\chi_p}}{(1 + \pi_t)} \right)^{1-\epsilon} + (1 - \phi_p) \left(\frac{P_{i,t}}{P_t} \right)^{1-\epsilon}. \quad (69)$$

Finally, the relationship between domestic demand and supply of final goods is given by

$$da_t disp_t = y_{S,t}, \quad (70)$$

where $disp_t \geq 1$ is the inefficiency attributed to price dispersion and $y_{S,t}$ is the aggregate supply of the composite goods, defined as

$$y_{s,t} = \left[(1 - \alpha_d)^{1/\theta_d} (y_t - x_t)^{1-1/\theta_d} + (\alpha_d)^{1/\theta_d} (y_{f,t})^{1-1/\theta_d} \right]^{\frac{\theta_d}{\theta_d-1}}. \quad (71)$$

Again using the properties of Calvo's pricing mechanism, this price dispersion term evolves as

$$disp_t = \phi_p \left(\frac{(1 + \pi_{t-1})^{\chi_p}}{(1 + \pi_t)} \right)^{-\epsilon} disp_{t-1} + (1 - \phi_p) \left(\frac{P_{i,t}}{P_t} \right)^{-\epsilon}. \quad (72)$$

Appendix 4. Complete Set of Equilibrium Conditions

The equilibrium for the model economy, given macroeconomic policy rules for R_t^{IB} and s_t^{MA} , is a sequence for c_t , h_t , $\frac{M_t}{P_t}$, R_t^D , rer_t , $\frac{W_t}{P_t}$, y_t , $\frac{P_{y,t}}{P_t}$, $rr_{K,t}$, k_{t+1} , inv_t , $k_{D,t+1}$, $k_{D,t+1}^{new}$, qr_t , $payr_t$, $f sr_t$, $f(\bar{\omega}_t, \sigma_\omega)$, $g(\bar{\omega}_t, \mu_t, \sigma_\omega)$, $\bar{\omega}_t$, μ_t , b_t , $netr_t$, $\rho(\bar{\omega}_t, \mu_t, \sigma_\omega)$, $defr_{ate}_t$,

$recov_t, c_{K,t}, lq_t, n_t, xrt_t, s_t, D_t/P_t, fr_t, gr_t, da_t, y_{s,t}, x_t, y_{f,t}, mgr_t, \pi_t, B_t^*, P_{i,t}/P_t, \Omega_{1,t}, \Omega_{2,t}, dispt_t$, such that the following conditions are satisfied:

$$1 = \beta R_t^D E_t \left[\frac{u_{c,t+1}}{u_{c,t}} \frac{1}{(1 + \pi_{t+1})} \right] \quad (73)$$

$$1 = \beta R_t^* \Theta(B_t^*) E_t \left[\frac{u_{c,t+1}}{u_{c,t}} \frac{rer_{t+1}}{rer_t} \frac{1}{(1 + \pi_{t+1}^*)} \right] \quad (74)$$

$$u_{\frac{M}{P},t} = \frac{R_t^D - 1}{R_t^D} u_{c,t} \quad (75)$$

$$\frac{W_t}{P_t} = - \frac{u_{h,t}}{u_{c,t}} \quad (76)$$

$$y_t = a_t (k_t)^{\theta_y} (h_t)^{1-\theta_y} \quad (77)$$

$$\frac{W_t}{P_t} = \frac{P_{y,t}}{P_t} \frac{(1 - \theta_y) y_t}{h_t} \quad (78)$$

$$rr_{K,t} = \frac{P_{y,t} \theta_y y_t}{P_t k_t} \quad (79)$$

$$k_{t+1} = (1 - \delta) (k_t - k_{D,t}^{new}) + \left(1 - \Delta \left(\frac{inv_t}{inv_{t-1}} \right) \right) inv_t + \eta_K (1 - \delta) k_{D,t} \quad (80)$$

$$k_{D,t} = (1 - \eta_K) (1 - \delta) k_{D,t-1} + k_{D,t}^{new} \quad (81)$$

$$qr_t \left(1 - \Delta \left(\frac{inv_t}{inv_{t-1}} \right) - \Delta' \left(\frac{inv_t}{inv_{t-1}} \right) \frac{inv_t}{inv_{t-1}} \right) + \beta E_t \left[\frac{u_{c,t+1}}{u_{c,t+1}} qr_{t+1} \left(\Delta' \left(\frac{inv_{t+1}}{inv_t} \right) \left(\frac{inv_{t+1}}{inv_t} \right)^2 \right) \right] = 1 \quad (82)$$

$$\mu_t = \frac{(qr_t - fsr_t) (1 - \delta)}{payr_t} \quad (83)$$

$$payr_t = (rr_{K,t} + (1 - \delta) qr_t) \quad (84)$$

$$f(\bar{\omega}_t, \sigma_\omega) = \int_{\bar{\omega}_t}^{\infty} \omega d\Phi(\omega; \sigma_\omega) - \bar{\omega}_t (1 - \Phi(\bar{\omega}_t; \sigma_\omega)) \quad (85)$$

$$g(\bar{\omega}_t, \mu_t, \sigma_\omega) = \bar{\omega}_t(1 - \Phi(\bar{\omega}_t; \sigma_\omega)) + (1 - \mu_t) \int_0^{\bar{\omega}_t} \omega d\Phi(\omega; \sigma_\omega) \quad (86)$$

$$(1 + \pi_t) \text{payr}_t k_t g(\bar{\omega}_t, \mu_t, \sigma_\omega) = R_{t-1}^{IB} b_{t-1} \quad (87)$$

$$b_t = (qr_t k_{t+1} - \text{netr}_t) \quad (88)$$

$$\begin{aligned} & qr_t E_t \left\{ R_t^{IB} \frac{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_\omega)}{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \right\} \\ &= E_t \left\{ \frac{(1 + \pi_{t+1}) \text{payr}_{t+1}}{\rho(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \frac{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_\omega)}{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_\omega)} \right\} \end{aligned} \quad (89)$$

$$\rho(\bar{\omega}_t, \mu_t, \sigma_\omega) = \left[g(\bar{\omega}_t, \mu_t, \sigma_\omega) - f(\bar{\omega}_t, \sigma_\omega) \frac{g_{\bar{\omega}}(\bar{\omega}_t, \mu_t, \sigma_\omega)}{f_{\bar{\omega}}(\bar{\omega}_t, \sigma_\omega)} \right]^{-1} \quad (90)$$

$$\text{recov}_t = \frac{(1 - \mu_t) \int_0^{\bar{\omega}_t} \omega d\Phi(\omega; \sigma_\omega) \text{payr}_t k_t (1 + \pi_t)}{\Phi(\bar{\omega}_t, \sigma_\omega) [R_{t-1}^{IB} b_{t-1}]} \quad (91)$$

$$\text{defrate}_t = \Phi(\bar{\omega}_t, \sigma_\omega) \quad (92)$$

$$\text{netr}_t = (1 - \lambda) f(\bar{\omega}_t, \sigma_\omega) \text{payr}_t k_t + \tau_E \quad (93)$$

$$c_{K,t} = \lambda f(\bar{\omega}_t, \sigma_\omega) \text{payr}_t k_t \quad (94)$$

$$lq_t = \nu k_{D,t} \quad (95)$$

$$k_{D,t}^{\text{new}} = k_t \int_0^{\bar{\omega}_t} \omega d\Phi(\omega; \sigma_\omega) \quad (96)$$

$$lq_t = Z(n_t)^{1-\alpha_{lq}} \quad (97)$$

$$lq_t = Z_{xr}(xr_t)^{1-\alpha_{xr}} \quad (98)$$

$$fsr_t = \eta_K qr_t - \nu(fr_t + gr_t) + (1 - \eta_K)(1 - \delta)\beta E_t \left[\frac{u_{c,t+1}}{u_{c,t+1}} fsr_{t+1} \right] \quad (99)$$

$$fr_t = \frac{(n_t)^{\alpha_{lq}}}{Z(1 - \alpha_{lq})} \quad (100)$$

$$\frac{R_t^{IB}}{R_t^D} = gr_t \frac{(1 - \alpha_{xr}) lq_t}{xr_t} \quad (101)$$

$$\frac{[R_t^D - (1 - s_t) R_t^{IB} - s_t^{MA} R_t^{RE}]}{R_t^D} = gr_t \frac{(1 - \alpha_{xr}) l q_t}{xr_t} (s_t - s_t^{MA}) \quad (102)$$

$$xr_t = (s_t - s_t^{MA}) \frac{D_t}{P_t} \quad (103)$$

$$\frac{D_t}{P_t} (1 - s_t) = b_t \quad (104)$$

$$\Omega_{1,t} = mgcr_t + \beta \phi_p E_t \left\{ \left(\frac{(1 + \pi_t)^{\chi_p}}{(1 + \pi_{t+1})} \right)^{-\varepsilon} \frac{da_{t+1}}{da_t} \frac{u_{c,t+1}}{u_{c,t+1}} \Omega_{1,t+1} \right\} \quad (105)$$

$$\begin{aligned} \Omega_{2,t} = & \frac{P_{i,t}}{P_t} + \beta \phi_p E_t \left\{ \left(\frac{(1 + \pi_t)^{\chi_p}}{(1 + \pi_{t+1})} \right)^{1-\varepsilon} \left(\frac{P_{i,t}/P_t}{P_{i,t+1}/P_{t+1}} \right) \right. \\ & \times \left. \frac{da_{t+1}}{da_t} \frac{u_{c,t+1}}{u_{c,t+1}} \Omega_{2,t+1} \right\} \end{aligned} \quad (106)$$

$$(\varepsilon - 1) \Omega_{2,t} = \varepsilon \Omega_{1,t} \quad (107)$$

$$1 = \phi_p \left(\frac{(1 + \pi_{t-1})^{\chi_p}}{(1 + \pi_t)} \right)^{1-\varepsilon} + (1 - \phi_p) \left(\frac{P_{i,t}}{P_t} \right)^{1-\varepsilon} \quad (108)$$

$$da_t disp_t = y_{s,t} \quad (109)$$

$$disp_t = \phi_p \left(\frac{(1 + \pi_{t-1})^{\chi_p}}{(1 + \pi_t)} \right)^{-\varepsilon} disp_{t-1} + (1 - \phi_p) \left(\frac{P_{i,t}}{P_t} \right)^{-\varepsilon} \quad (110)$$

$$da_t = c_t + c_{K,t} + inv_t + n_t \quad (111)$$

$$y_{s,t} = \left[(1 - \alpha_d)^{1/\theta_d} (y_t - x_t)^{1-1/\theta_d} + (\alpha_d)^{1/\theta_d} (y_{f,t})^{1-1/\theta_d} \right]^{\frac{\theta_d}{\theta_d-1}} \quad (112)$$

$$mgcr_t = \left[(1 - \alpha_d) \left(\frac{P_{y,t}}{P_t} \right)^{1-\theta_d} + (\alpha_d) (rer_t)^{1-\theta_d} \right]^{\frac{1}{1-\theta_d}} \quad (113)$$

$$\frac{y_t - x_t}{y_{f,t}} = \frac{(1 - \alpha_d)}{\alpha_d} \left(\frac{rer_t}{P_{y,t}/P_t} \right)^{\theta_d} \quad (114)$$

$$rer_t B_t^* = R_{t-1}^* \Theta(B_{t-1}^*) \frac{B_{t-1}^*}{(1 + \pi_t^*)} rer_t - \frac{P_{y,t}}{P_t} x_t + rer_t (y_{f,t}) \quad (115)$$

$$x_t = \bar{x} \left(\frac{rer_t}{P_{y,t}/P_t} \right)^{\theta^*} . \quad (116)$$

Appendix 5. Interest Rate Shocks with Only One Friction

In this appendix, we show that, for our specific world interest rate shocks, IT is the optimal policy for a model with nominal frictions and that a countercyclical reserve requirement is also the best response with only financial (and no nominal) frictions.

Welfare Gains of Inflation Targeting without Financial Frictions

We subtract from the baseline model any features related to the financial accelerator mechanism. Table 9 shows the welfare gains of the inflation-targeting regime compared with the standard Taylor rule.

Welfare Gains of Countercyclical Reserve Requirement without Price Rigidities

Note that this exercise is equivalent to comparing the welfare under the inflation-targeting regime with inflation targeting and countercyclical reserve requirement in the baseline model. These results are reproduced in table 10.

Table 9. Welfare Comparison under Only Price Rigidities

Policy Framework	Welfare	Ranking	λ
Standard Taylor-Type Rule	−85.29	2	18.3%
IT Regime	−76.71	1	13.7%

Table 10. Welfare Comparison under Only Financial Frictions

Policy Framework	Welfare	Ranking	λ
Constant RR	−83.5624	2	6.4%
Countercyclical RR	−75.0940	1	1.8%

Appendix 6. Extension with Foreign Funding for Lending Intermediaries and Entrepreneurs

In contrast to other studies, and to boost balance sheet effects, we can allow for the possibility that the financial intermediaries use foreign funds to finance entrepreneurs besides the interbank market. For simplicity, we assume the amount of external funds available in each period for the lending intermediaries is constant in foreign currency ($\bar{b}_{LI}^*$). Likewise, the entrepreneurs also have access to external funds to finance their investment in capital. Again, we consider that the amount of external funds for the entrepreneurs is constant in foreign currency ($\bar{b}_E^*$). Since in equilibrium

$$E_t \left[\frac{R_t^{IB}}{1 + \pi_{t+1}} \right] \geq E_t \left[\frac{R_t^* \Theta_t}{1 + \pi_{t+1}^*} \frac{rer_{t+1}}{rer_t} \right],$$

both lending intermediaries and entrepreneurs will use the complete amount of external funds each period. The presence of these external funds will imply a direct balance sheet effect of exchange rate movements, which can magnify the impact of capital flows through the financial accelerator mechanism.

Thus, the loan contract now solves the following maximization problem:

$$\begin{aligned} & \text{Max } E_t \{ \text{payr}_{t+1} k_{t+1} f(\bar{\omega}_{t+1}, \sigma_t) \} \\ & \text{s.t. } \text{payr}_{t+1} k_{t+1} g(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_t) \\ & \geq \frac{R_t^{IB}}{1 + \pi_{t+1}} (b_t - rer_t \bar{b}_{LI}^*) + \frac{R_t^* \Theta_t}{1 + \pi_{t+1}^*} \frac{rer_{t+1}}{rer_t} \bar{b}_{LI}^* \end{aligned} \quad (117)$$

for all states in $t + 1$, where $b_t = (qr_t k_{t+1} - netr_t - rer_t \bar{b}_E^*)$ is the domestic loan to the entrepreneurs with net worth $netr_t$.

The equilibrium condition for the loan contract and entrepreneurs' variables are stated as follows. Arbitrage condition for the loans to entrepreneurs:

$$\begin{aligned} & qr_t E_t \left\{ \left[\frac{R_t^{IB}}{1 + \pi_{t+1}} \right] \frac{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_t)}{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_t)} \right\} \\ & = E_t \left\{ \frac{\text{payr}_{t+1}}{\rho(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_t)} \frac{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_t)}{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_t)} \right\}. \end{aligned} \quad (118)$$

Definition of the recovery rate of financial intermediaries' loans:

$recov_t$

$$= \frac{(1 - \mu_t) \int_0^{\bar{\omega}_t} \omega d\Phi(\omega, \sigma_{t-1}) payr_t k_t (1 + \pi_t)}{\Phi(\bar{\omega}_t; \sigma_{t-1}) \left[R_{t-1}^{IB} (b_{t-1} - rer_{t-1} \bar{b}_{LI}^*) + \frac{R_{t-1}^* \Theta_{t-1} (1 + \pi_t) rer_t}{1 + \pi_t^*} \bar{b}_{LI}^* \right]}. \quad (119)$$

Definition of the risk premium:

$$\rho(\bar{\omega}_t, \mu_t, \sigma_{t-1}) = \left[g(\bar{\omega}_t, \mu_t, \sigma_{t-1}) - f(\bar{\omega}_t, \sigma_{t-1}) \frac{g_{\bar{\omega}}(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_t)}{f_{\bar{\omega}}(\bar{\omega}_{t+1}, \sigma_t)} \right]^{-1}. \quad (120)$$

Budget constraints of entrepreneurs:

$$b_t = qr_t k_{t+1} - netr_t - rer_t \bar{b}_E^*. \quad (121)$$

Breakeven condition for financial intermediaries:

$$g(\bar{\omega}_t, \mu_t, \sigma_{t-1}) payr_t k_t = \left[\frac{R_{t-1}^{IB}}{1 + \pi_t} \right] (b_{t-1} - rer_{t-1} \bar{b}_{LI}^*) + \left[\frac{R_{t-1}^* \Theta_{t-1} rer_t}{1 + \pi_t^*} \right] \bar{b}_{LI}^*. \quad (122)$$

Real net worth of entrepreneurs:

$$netr_t = (1 - \lambda) \left(f(\bar{\omega}_t, \sigma_{t-1}) payr_t k_t - \frac{R_{t-1}^* \Theta_{t-1} rer_t}{1 + \pi_t^*} \bar{b}_E^* \right) + \tau_E. \quad (123)$$

Again, all entrepreneurs receive a lump-sum transfer, τ_E , but now they also make an interest payment for the constant amount of foreign debt $\bar{b}_E^*$ taken each period. Thus, a real appreciation of the currency increases the resources of entrepreneurs, improving their financial position and the demand for investment. As before, when an entrepreneur dies, which happens with a rate λ , he consumes all his wealth. Thus, consumption of entrepreneurs is

$$c_{K,t} = \lambda \left(f(\bar{\omega}_t, \sigma_{t-1}) payr_t k_t - \frac{R_{t-1}^* \Theta_{t-1} rer_t}{1 + \pi_t^*} \bar{b}_E^* \right) \quad (124)$$

$$\frac{D_t}{P_t} (1 - s_t) = (b_t - rer_t \bar{b}_{LI}^*). \quad (125)$$

Appendix 7. Financial Dollarization of the Entrepreneurs' Loans

Another modification of the baseline model can be the possibility that the loan contract to the entrepreneurs is set in or indexed to foreign currency (dollars). Under this situation, we define $\psi \in [0, 1]$ as the fraction of the loan set in domestic currency and $1 - \psi$ as the fraction of the loan in foreign currency. For the exercise reported, we consider $\psi = 0.5$.

Thus, the loan contract now solves the following problem:

$$\begin{aligned} & \text{Max} E_t \{ \text{payr}_{t+1} k_{t+1} f(\bar{\omega}_{t+1}, \sigma_t) \} \\ & \text{s.t. } \text{payr}_{t+1} k_{t+1} g(\bar{\omega}_{t+1}, \mu_{t+1}, \sigma_t) \\ & \geq \left(\psi \frac{R_t^{IB}}{1 + \pi_{t+1}} + (1 - \psi) \frac{\tilde{R}_t^*}{1 + \pi_{t+1}^*} \frac{rer_{t+1}}{rer_t} \right) b_t \end{aligned} \quad (126)$$

for all states in $t + 1$, where $\tilde{R}_t^* = R_t^{IB} E_t \left[\frac{rer_t}{rer_{t+1}} \frac{(1 + \pi_{t+1}^*)}{(1 + \pi_t^*)} \right]$ is the ex ante real interest rate in terms of the foreign currency. We then find the first-order conditions of this problem as we did in appendix 1.

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Measuring the Natural Interest Rate for the Turkish Economy*

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This paper measures the natural interest rate for the Turkish economy as an unobserved stochastic variable. In doing so, the study adopts a systems approach, based on a parsimonious New Keynesian model consisting of a Phillips curve, an IS curve, and a backward-looking Taylor-type interest rate rule linking the real interest rate to the natural interest rate. The model also includes stochastic laws of motion for the natural interest rate and potential output. As a contribution to the existing literature on natural interest rate and in view of the volatile nature of the Turkish economy, the parameters are assumed to be time varying. However, the requirement to simultaneously estimate parameters and to solve the state-space problem introduces non-linearity to the model. The issue of non-linearity can be handled by employing the extended Kalman filter (EKF), i.e., the use of standard Kalman filter equations to the first-order Taylor approximation of the non-linear model about the last estimate. Estimation results suggest that both the estimated natural interest rate and the real interest rate series move in tandem with the real interest rate. All the derived series are plausible and capture the significant turning points of the economy. As for the time-varying parameters, the estimated coefficients are reasonable. Overall, findings of this study provide guidance for future research on the natural interest rate, an important tool for monetary policy, and lay the basis for further work that may adopt the EKF algorithm. Most importantly, this study underlines the need to assess the stance of the monetary policy by using the natural interest rate.

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“One problem is that [the policymaker] cannot know what the ‘natural’ rate is. Unfortunately, we have as yet devised no method to estimate accurately and readily the natural rate of either interest or unemployment. And the ‘natural’ rate will itself change from time to time.”

Friedman (1968)

1. Introduction

Policymakers are facing the growing challenge to foresee the future course of price dynamics in fulfilling their commitment to maintain price stability. In doing so, another challenge that is encountered by policymakers is to gather and employ all the relevant information in the data set in order to evaluate the monetary policy stance. Due to the overriding emphasis on price stability and the associated use of monetary policy rules based on short-term policy rates over the last decades, the natural interest rate has become a useful benchmark for assessing the monetary policy stance and determining whether the current level of the interest rate is expansionary or contractionary for the economic activity. Besides, policy rates in advanced economies hit the zero lower bound¹ amid the unconventional monetary policy implementations after the global crisis,^{2,3} drawing renewed attention to the natural interest rate,

¹Zero lower bound is the situation when the short-term nominal interest rate hits or nears zero, causing a liquidity trap in the economy.

²The global crisis in 2008 is considered to be the worst financial crisis since the Great Depression and led to the Great Recession, which was felt across the globe.

³The global crisis challenged central banks in advanced economies in the conduct of monetary policy. Prior to the crisis, central banks used the short-term policy rates as their primary instrument of monetary policy, by lowering the rate to provide stimulus and raising it to slow economic activity and control inflation. In addition, central banks also had the option to exercise monetary policy via required reserves and open market operations. But after the global crisis, reducing policy rates further to induce production was no longer an option as policy rates hit the zero lower bound. Meanwhile, reserve requirements could not be reduced radically against financial stability risks. In turn, central banks were left with the only option—to expand the money supply through open market operations. In periods of crisis, however, government securities tend to become bid up due to their perceived safety, which limits their effectiveness as a policy tool. Hence, major central banks had to resort to quantitative easing as well as credit

which is estimated to have been low for a prolonged period of time.⁴

The natural interest rate is the real interest rate that would prevail if there were no inflationary or deflationary pressures requiring the central bank to lean in either direction (Archibald and Hunter 2001). In other words, the natural interest rate is the real interest rate consistent with stable output and inflation, thus implying a neutral monetary policy stance. Accordingly, a real interest rate above (below) the natural rate for a prolonged period of time means lower (higher) consumption and investment, which would eventually decrease (increase) output and inflation in the absence of other shocks to the economy (Laubach and Williams 2003; De Fiore and Tristani 2011). Thus, it is vital to quantify the level of the natural interest rate in assessing the monetary policy stance.

The natural interest rate was originally defined by Wicksell (1898) as a certain rate of interest on loans, which is neutral⁵ in

easing, which correspond to balance sheet policies comprising large-scale asset purchases and long-term funding with the objective to affect long-term interest rates and ease banks' collateral and funding liquidity constraints (Smaghi 2009). The unconventional monetary policy tools in the post-crisis period also included forward guidance, which was used effectively by the Federal Reserve (Fed) and other major central banks to affect long-term interest rates (Bernanke 2013).

⁴Blanchard, Furceri, and Pescatori (2014) discuss that the natural interest rate fell sharply after the global crisis due to several factors. These may be listed as the collapse of financial intermediation and the increase in uncertainty, which had effects on precautionary savings and investment; higher risk and market risk aversion, which led to a reduced safe rate relative to the rate on risky assets; and the monetary policy, which prevented the actual rate from declining as much as the natural rate due to the zero lower bound on nominal rates and low inflation.

⁵The terms "natural" and "neutral" are used interchangeably in earlier studies on natural interest rate theories (Laubach and Williams 2003; Williams 2003; Amato 2005; Hamilton et al. 2015; Olson and Wessel 2015), whereas equilibrium interest rate and Wicksellian interest rate are other terms that are used as substitutes for natural interest rate. Yet, Ferguson (2004) and Hamilton et al. (2015) criticize the multiplicity of these terms, while Pescatori and Turunen (2015) note the subtle conceptual differences among these terms. Garrison (2006) distinguishes between natural and neutral interest rate by underlining that these seemingly synonymous terms provide a contrast between pre-Keynesian and post-Keynesian thinking. In particular, Keynes (1936) makes an important distinction

the sense that it neither raises nor lowers the commodity prices. Put differently, this is the rate of interest that would be determined by supply and demand conditions if no use were made of money and all lending were effected in the form of real capital goods. In that sense, natural interest rate corresponds to the current value of the natural interest rate on capital.

The seminal work of Wicksell (1898) contributed greatly to the understanding of the role of interest rate in income and price dynamics. This pioneering work also induced further research and launched controversial debates on the natural interest rate.⁶ However, in the second half of the twentieth century, natural interest rate was less tempting, as unemployment became the new focus of attention with the work by Phelps (1967) and Friedman (1968).⁷

It was only through the increased emphasis on price stability by policymakers and the influential work of Taylor (1993), which proposed a simple interest rate rule based on natural rates, that the concept of natural interest rate was revived and given significant consideration in both the academic and the policymaking front.^{8,9}

between neutral and natural interest rate. Accordingly, neutral interest rate is the equilibrium interest rate where the elasticity of employment is zero. On the other hand, natural interest rate is the rate of interest that equates savings and investment while also maintaining a stable price level. Yet, the natural rate, according to Keynes (1936), is not unique, whereas if any rate is unique, it is the neutral rate.

⁶Wicksell's theory had a strong influence on Cassel (1903), Keynes (1936), and Hayek (1939).

⁷Layard, Nickell, and Jackman (1991), Laxton and Tetlow (1992), Weiner (1993), Kuttner (1994), King, Stock, and Watson (1995), Gordon (1997), Nickell (1997), Staiger, Stock, and Watson (1997a, 1997b), Stiglitz (1997), Cross, Darby, and Ireland (1998), Gerlach and Smets (1999), Richardson et al. (2000), Laubach (2001), Ball and Mankiw (2002), and Benes and N'Diaye (2004) are succeeding works on natural rate theories of unemployment.

⁸Taylor (1993) proposed a simple monetary policy rule that stipulates how much the central bank should change the nominal interest rate in response to changes in inflation and output. The rule postulates that the nominal interest rate i_t should respond to divergences of actual inflation rate from target inflation and actual GDP from potential GDP in the following form, where $i_t = r_t^* + \pi_t + 0.5(\pi_t + \pi_t^*) + 0.5ygap_t$. Here, i_t is the policy rate; r_t^* is the equilibrium real interest rate (the natural interest rate); π_t is the inflation rate (GDP deflator); π_t^* is the desired (target) rate of inflation; and $ygap_t$ is the output gap.

⁹The Taylor rule became highly controversial after the global crisis. In particular, Taylor (2015) asserts that the Fed kept interest rates much lower than

On the policymaking front, the priority of central banks to maintain price stability by the adoption of an inflation-targeting regime in both advanced and emerging economies over the last decade designated the natural interest rate as a convenient benchmark that policy rates can be measured against directly.

On the academic front, the concept of natural interest rate was invigorated especially after Woodford (2003), which focused on the gap between the current level of the natural interest rate and the interest rate controlled by the central bank as the key variable for the analysis of inflationary or deflationary pressures. In other words, the monetary policy authority should adjust its policy instrument in response to deviations of output and employment from their natural levels.

Natural rate has gained significance after the global crisis, given the persistently low interest rates in advanced economies amid unconventional monetary policy practices. In particular, the exceptionally near-zero interest rates have prompted the question of whether low interest rates will be a permanent feature of the future economic outlook (Bernanke 2015b; Laubach and Williams 2015). Accordingly, natural interest came to the forefront amid intense debates about why it may continue to be low in the future.¹⁰

prescribed by the Taylor rule during 2003–05. This caused the housing bubble and other financial excesses, which eventually evolved into the global crisis in 2008. Taylor (2015) also argues that the Fed's monetary policy since the financial crisis has been too easy and discretionary, especially with regards to the implementation of the quantitative easing policies, and this caused the Fed to abide by the zero interest rate policy longer than envisioned by the rule. Bernanke (2015b), on the other hand, claims that a modified Taylor rule, which comprises core inflation and higher weight on output gap, is more descriptive of the Fed's policy during the last two decades. Yet, this modified rule envisions a negative interest rate in the post-crisis period, which, according to Bernanke (2015a), is not feasible. Obviously, this warrants keeping interest rates at the zero lower bound while providing additional monetary easing via unconventional tools.

¹⁰Summers (2013, 2016) argues that the decline in natural interest rate may be defended by the secular stagnation view. Originally developed by Hansen (1939) to describe the stagnant 1930s, the view asserts that secular stagnation occurs due to the imbalance between higher propensity to save and lower propensity to invest. This results in excessive saving that pulls down real interest rates and also the natural interest rate. Bernanke (2015c) justifies the decline on the basis of the savings-glut view that rationalizes the fall by excess global savings emanating largely due to China and other Asian emerging market economies and oil-producing countries. Krugman (2013) explains decreasing rates by the

Meanwhile, these extraordinary monetary policy tools implemented in advanced economies led to massive global liquidity, which compelled many emerging economies to adjust their monetary policy framework in order to address financial stability concerns posed by volatile capital flows.¹¹ Accordingly, central banks of emerging economies, including Turkey,¹² resorted to macroprudential tools in order to observe financial stability besides maintaining the price stability objective.

Yet, recently, monetary policy across advanced economies has diverged as U.S. monetary policy has started to normalize with a policy rate liftoff while monetary policies in other major economies have continued to be expansionary.¹³ This poses additional challenges to

liquidity trap, whereas Reinhart, Reinhart, and Rogoff (2012) ascribe lower rates to debt overhangs. Gordon (2012) attributes the decline to lower productivity growth, while Kasparov and Thiel (2012) validate it by the innovation stagnation.

¹¹The unconventional policy tools employed by advanced economies after the crisis led to post-crisis spillovers, causing massive capital flows to emerging economies. This resulted in rapid credit growth, which posed risks to financial stability. Heightened concerns about financial stability triggered a search for an alternative monetary policy framework in small open economies, including Turkey (International Monetary Fund (IMF) 2012; Akçelik et al. 2013; Kara 2013).

¹²The Central Bank of the Republic of Turkey (CBRT) was prompted by the global crisis to adopt financial stability as a supplementary objective to its primary goal of maintaining price stability. The framework was centered on containing the adverse effects of rapid credit growth and the associated macrofinancial risks by using several tools jointly in the new monetary policy mix that included policy rate, the interest rate corridor, and required reserves (Başçı and Kara 2011; IMF 2012; Akçelik et al. 2013; Alper, Kara, and Yörükoğlu 2013a). Also, liquidity policy was used effectively along with the reserve options mechanism, which was engineered as a unique macroprudential tool (Küçüksaraç and Özel 2012; Alper, Kara, and Yörükoğlu 2013b; Oduncu, Akçelik, and Ermişoğlu 2013).

¹³The exit from the prolonged use of unconventional monetary policies by advanced economies in the post-crisis period was initiated by the Fed's recent policy rate hike. Yet, it should be noted that other major central banks seem to diverge from the Fed by continuing to ease their policies. In particular, the Bank of Japan and the European Central Bank have delivered a recent rate cut and have embarked upon more aggressive quantitative easing programs, with the former entering into negative territory while the latter has already ventured into the sub-zero zone since 2014. Also, central banks in other advanced economies have reduced their rates. In particular, Sveriges Riksbank, Danmarks Nationalbank, and the Swiss National Bank reduced their policy rates below zero. On the other hand, the Reserve Bank of New Zealand and Norges Bank cut their policy rates, where the latter warned about a likely negative interest rate. Also,

emerging market economies, especially Turkey,¹⁴ while having serious implications regarding the proper measurement of the natural interest rate and the assessment of the monetary policy stance.

Despite the increased need for an accurate measure of the natural interest rate as a useful monetary policy guide, its unobservable nature and the considerable uncertainty associated with its estimation creates many difficulties.¹⁵ These are particularly severe in the case of structural breaks, which cause natural rates to vary unpredictably amid higher uncertainty (Staiger, Stock, and Watson 1997a; Orphanides and van Norden 2002; Laubach and Williams 2003).

In spite of these problems, there are numerous techniques developed to measure the natural interest rate. Among these, one simple method is to calculate the average real interest rate, which is considered to be a proxy for the natural interest rate when taken over a long period of time.¹⁶ Yet, this technique is too basic, as it ignores

Czech National Bank raised the possibility of introducing negative rates. Despite these divergences, evidence shows larger international interest rate spillovers for U.S. policy announcements than those for other central banks, which marks the Fed's policy rate liftoff as a crucial step towards normalization of global monetary policies (Ehrmann and Fratzscher 2005; Rogers, Scotti, and Wright 2014; Fischer 2015).

¹⁴The CBRT released a road map in August 2015 regarding the policies to be implemented during the normalization of the global monetary policies (CBRT 2015b). The road map included simplification steps for the Turkish lira (TL) liquidity management, and also contained measures for managing foreign exchange (FX) liquidity and supporting financial stability. These measures were reiterated in the CBRT's press release in December 2015, addressing the monetary and exchange rate policy for 2016 (CBRT 2015a).

¹⁵The estimation of natural interest rate is challenging, as it varies over time in response to shifts in preferences and technology (Berger and Weber 2012). Besides, changes in other factors, such as fiscal policy, may induce persistent changes in the natural interest rate (Laubach and Williams 2003). Orphanides and Williams (2002) discuss that problems pertaining to the estimation of the natural interest rate had already been brought up by Friedman (1968), who acknowledged that the policymaker cannot know the level of the natural rate, that no method was devised to estimate it accurately and readily, and that it also changes over time. Wicksell (1898) and Cassel (1928) also argued that the central bank cannot know what the equilibrium rate of interest is and that it is not fixed or unalterable.

¹⁶Taylor (1993) assumes an equilibrium real interest rate at 2 percent, which is close to the average of the steady-state growth rate of 2.2 percent. Reifschneider and Williams (2000) estimate natural interest rate for the U.S. economy by

persistent changes in demand and supply factors that cause large movements in the natural interest rate. Besides, by treating the natural interest rate as constant, this method also ignores structural breaks and regime switches (Baksa et al. 2013). Hence, a relatively more advanced technique in this regard is to compute the multi-year averages in moving-average terms, which allows for time variation in the natural interest rate (Hamilton et al. 2015; Laubach and Williams 2015).

Other simple estimation methods may include conventional filtering techniques, such as the Hodrick-Prescott filter and the bandpass filter,¹⁷ which decompose the real interest rate series to its cyclical and trend components (Borio, English, and Filardo 2003; Muinhos and Nakane 2006; Barcellos Neto and Portugal 2009). Despite their simplicity, Orphanides and Williams (2002) report that these univariate filters are sensitive to final observations. This is also argued by St. Amant and van Norden (1997), Orphanides and van Norden (2002), van Norden (2002), and Christiano and Fitzgerald (2003).

In addition to these simple univariate techniques, natural interest rate may also be estimated with the adoption of a monetary model with microfoundations having a money-in-the-utility specification of money demand (Andres, López-Salido, and Valles 2006; Andres, López-Salido, and Nelson 2009; Berger and Weber 2012). Alternatively, the natural interest rate may be computed by large-scale econometric models such as MIT-Penn-SSRC (MPS) or the FRB/US models of the U.S. economy.¹⁸

Moreover, natural interest rate can also be measured using economic theory. This may be in the context of the capital asset pricing model (Browne and Everett 2006; Fuentes and Gredig 2007) or those based on estimates of the marginal productivity of capital (Chadha

taking the average of the real funds rate over the 1960–98 period. Hamilton et al. (2015) assume that the average real interest rate, when taken over a sufficiently long period of time, will approximate the equilibrium rate, which equals the natural interest rate at steady-state level of output. Behera, Pattanaik, and Kavediya (2015) also argue that the average real interest can be used as a proxy for the natural rate.

¹⁷For further details, see Hodrick and Prescott (1997), Baxter and King (1999), and Christiano and Fitzgerald (2003).

¹⁸Bomfim (1997) estimates natural interest rate using the MPS model, while Bomfim (1998) uses the FRB/US model.

and Nolan 2001). Also, natural interest rate may be derived using the uncovered interest rate parity condition (Fuentes and Gredig 2007) or total factor productivity growth where an expected increase in total factor productivity is assumed to raise the natural interest rate and vice versa (Woodford 2003; Amisano and Tristani 2008; Galí 2008; Justiniano and Primiceri 2010; Lundvall and Westermarck 2011; Carlstrom and Fuerst 2016).¹⁹

Besides these models, natural interest rate may also be computed by structural vector autoregressive (SVAR) models. Brzoza-Brzezina (2002) applies an SVAR model to estimate natural interest rate.²⁰ Accordingly, a two-component SVAR model is constructed for the GDP increment (as an approximation of the output gap) and the real interest rate, where the model calculates unobserved shocks, of which one corresponds to the equilibrium interest rate and the other corresponds to the disequilibrium component of the interest rate.

Alternatively, the natural interest rate may be estimated by time-varying parameter vector autoregressive (TVP-VAR) models that enable the study of the complex relationships among macroeconomic data, allowing for the lagged coefficients and the variances of the economic shocks to vary over time. However, the TVP-VAR model fails to impose sufficient economic structure, even though it captures a variety of non-linear behaviors that are apparent in macroeconomic time series (Lubik and Matthes 2015).

The natural interest rate has also been commonly estimated via more sophisticated procedures like dynamic stochastic general

¹⁹This relates to the Wicksellian view defining natural interest rate as the rate of interest that equates savings with investment. The Wicksellian view also treats the natural interest rate as the marginal productivity of capital and the rate of interest that is consistent with aggregate price stability, which fed into the neo-Wicksellian/New Keynesian view perceiving natural interest rate to be dependent on various economic factors. These factors are households' rate of time preference and their willingness to substitute consumption across time, the marginal productivity of capital (in particular, the level of the capital stock), and shocks that affect households' savings decisions such as innovations to total factor productivity and exogenous changes in government spending (Amato 2005). Important New Keynesian models along this line can be noted as Rotemberg and Woodford (1997, 1999), Erceg, Henderson, and Levin (2000), Smets and Wouters (2002), Amato and Laubach (2003a, 2003b, 2004), Giannoni and Woodford (2003), Neiss and Nelson (2003), Woodford (2003), and Giannoni (2007).

²⁰This is in the spirit of Blanchard and Quah (1989) and Claus (1999), who estimate potential output using SVAR.

equilibrium (DSGE) models with nominal rigidities.²¹ Accordingly, the natural interest rate is computed essentially via reverse engineering, by imposing that the output gap is equal to zero after a certain horizon, and then solving for the level of the interest rate that is consistent with this output gap.

The complexity of large-scale DSGE models encouraged the development of small-scale macroeconomic models that are easier to apply yet more structured than simple statistical approaches. In this respect, an alternative technique for estimating the natural interest rate was proposed by Laubach and Williams (2003), who use a simple small-scale macroeconomic model to jointly estimate the natural interest rate and the potential output. In doing so, the natural interest rate and the potential output are treated as unobserved variables in a multivariate unobserved-components model, where the Kalman filter features out as the appropriate estimation algorithm.²²

The Kalman filter has been used widely as a standard method to estimate natural interest rate. In particular, Orphanides and Williams (2002), Basdevant, Bjorksten, and Karagedikli (2004), Cuaresma, Gnan, and Ritzberger-Gruenwald (2004), Larsen and McKeown (2004), Clark and Kozicki (2005), Garnier and Wilhelmsen (2005), Benati and Vitale (2007), Bernhardsen and Gerdrup (2007), Fuentes and Gredig (2007), Mésonnier and Renne (2007a, 2007b), Barcellos Neto and Portugal (2009), and Humala and Rodríguez (2009), among many others, use the Kalman filter to compute natural interest rate for various advanced economies.

Despite the common use of the Kalman filter for estimating natural interest rate in advanced economies, which present rare incidences of excessive boom-bust cycles, the standard Kalman filter may fail to perform well in emerging market economies that are generally characterized by relatively higher volatility. Even though this volatility may be captured by assuming parameters to be time varying, the analysis requires the adoption of a non-linear state-space

²¹Smets and Wouters (2002), Giammarioli and Valla (2003), Neiss and Nelson (2003), Edge, Kiley, and Laforge (2008), Canzoneri, Cumby, and Diba (2012), Burgess et al. (2013), Barsky, Justiniano, and Melosi (2014), Cúrdia (2015), Cúrdia et al. (2015), and Del Negro et al. (2015) are previous works that estimate natural interest rate using DSGE models.

²²For further details, see Kalman (1960), Kalman and Bucy (1961), and Hamilton (1994a, 1994b).

form that impedes the use of the standard Kalman filter. This problem can be handled via the extended Kalman filter (EKF), which is a widely used algorithm for linearizing non-linear systems (Grillen-zoni 1993; Hamilton 1994b; McKiernan 1996; Bacchetta and Gerlach 1997; Pasricha 2006).

Accordingly, EKF has also been used for the Turkish economy, which also presents high volatility (Özbek, Özlale, and Öztürk 2003; Özbek and Özlale 2005; Sarıkaya et al. 2005; Kara, Küçük-Tuğçer et al. 2007; Kara, Ögünç et al. 2007; Us 2014). Yet, these studies utilize EKF to calculate output gap or NAIRU (non-accelerating rate of unemployment). Meanwhile, natural interest rate for the Turkish economy was computed solely by Ögünç and Batmaz (2009). However, this pioneering work fails to adopt a non-linear framework.

Hence, the absence of previous studies that estimate the natural interest rate by also considering the highly volatile nature of the Turkish economy leaves a gap for measuring the natural interest rate with time-varying parameters in a state-space form. This gap establishes the main motivation of this study. To the best of our knowledge, this is the first formal attempt to compute the natural interest rate for the Turkish economy in a non-linear setting.

This paper is conjectured to be useful in several ways. First of all, findings of this study provide guidance for future research on the natural interest rate, which is an important measure of the monetary policy stance. In addition, the study contributes to the existing literature by producing other significant variables like real interest rate, inflation, potential output, output, and the output gap. Moreover, the results shed light on the course of time-varying parameters that indicate inflation persistence, the contribution of demand- and supply-side factors to inflation, as well as the determinants of aggregate demand. But most importantly, this study underlines the need to assess the stance of the monetary policy by also using the natural interest rate.

It should be underlined that this paper does not intend to explain the evolution of interest rate dynamics in the Turkish economy, nor does it seek to determine the underlying structural forces driving the natural interest rate. Also, the paper does not attempt to explain output or price developments, but it solely tries to exploit the information contained in the data set in order to extract the unobservable natural interest rate by acknowledging that it is impossible

to measure it with precision. With this in mind, the paper still takes this endeavor to estimate the natural interest rate, perceiving it as a “heuristic benchmark” and “useful aid in thinking about monetary policy.”²³

It should also be kept in mind that the models tested in the paper are chosen according to their in-sample properties and the degree to which they are able to match the behavior of the original series. Thus, the model selection is based on the informal optimization of the plausibility of the resulting estimates, but without any regard to their forecasting properties.

The organization of the paper is as follows. The next section presents the benchmark model for the natural interest rate and its state-space representation as well as the alternative model specification, which is based on the inclusion of dynamic homogeneity condition as a robustness test. The third section discusses the estimation results and seeks to improve the findings by applying a smoothing algorithm and using alternative inflation target measures. Finally, the last section concludes this paper. The state-space representation of the EKF is in the appendix.

2. System Specification

Models that have been used to estimate natural interest rate are essentially based on a system of equations. In the spirit of Laubach and Williams (2003), the system is composed of a Phillips curve, which relates inflation to its lagged terms as well as the output gap and other supply-side factors that pose inflationary pressure; an IS curve that links output gap to real interest rate, the nominal exchange rate, and its lagged term; and a Taylor-type interest rate rule that connects the real interest rate to the natural interest rate, the deviation of inflation from the inflation target, and the output gap. The system also includes an identity for output besides equations defining the law of motion for potential output and the natural interest rate as well as equations defining their trend components.

²³See, respectively, Bean (2004) and Ferguson (2004).

2.1 Benchmark Model Specification

The benchmark model specification is based on a parsimonious version of a standard New Keynesian framework consisting of a Phillips curve, an IS curve, and an interest rate rule.²⁴ Given the highly volatile nature of the Turkish economy, the empirical framework departs from Laubach and Williams (2003) by assuming parameters to be time varying. The variables used in the benchmark model are as follows: π_t is the inflation rate (first difference of the log of consumer price index); z_t is a vector of supply-side variables (normally taken to be changes in import prices, real exchange rate, or the nominal exchange rate) that impose pressure on inflation; r_t is the real interest rate; y_t is the (log of) output level; r_t^* and y_t^* represent the natural interest rate and (the log of) potential output, respectively; while π_t^* is the inflation target. Finally, gap_t is the output gap.

The system is composed of the following equations.

Inflation is assumed to behave according to an accelerationist-type Phillips-curve equation such that

$$\pi_t = \alpha_{1,t}\pi_{t-1} + \alpha_{2,t}\pi_{t-2} + \alpha_{3,t}gap_{t-1} + \alpha_{4,t}z_t + \varepsilon_t^\pi. \quad (1)$$

According to the above equation, inflation is a function of built-in inflation, demand-pull inflation, and cost-push inflation that can be captured by the inclusion of lagged inflation terms, the output gap, and the change in nominal exchange rate, respectively.²⁵ The coefficients $\alpha_{1,t}$ and $\alpha_{2,t}$, which show the degree of inflation persistence, are expected to be greater than zero. The coefficients $\alpha_{3,t}$ and $\alpha_{4,t}$, which denote the degree of demand-pull and cost-push inflation, correspondingly, are also expected to be greater than zero. Obviously, ε_t^π is the disturbance term.

²⁴Ball (1998, 1999, 2000), Rudebusch and Svensson (1998), and Peersman and Smets (1999) present insightful examples of New Keynesian small-scale macroeconomic models.

²⁵Based on the triangle model of Gordon (1991), inflation has three root causes: built-in inflation (inflation results from past events and persists into the present), demand-pull inflation (falling unemployment rates or rising GDP feeds into inflation), and cost-push inflation (increases in the cost of goods and services raise inflation).

The IS curve that describes the aggregate demand can be expressed as follows:

$$ygap_t = \beta_{1,t}ygap_{t-1} + \beta_{2,t}r_{t-1} + \beta_{3,t}z_t + \varepsilon_t^{ygap}, \quad (2)$$

where $\beta_{1,t}$ is the coefficient of the autoregressive term, $\beta_{2,t}$ is the coefficient of the real interest rate, $\beta_{3,t}$ is the coefficient of the nominal exchange rate, and ε_t^{ygap} is the error term. $\beta_{1,t}$ and $\beta_{3,t}$ are positive, while $\beta_{2,t}$ is estimated to be negative.

The real interest rate is linked to the natural interest rate in the form of a backward-looking Taylor rule such that

$$r_t = r_{t-1}^* + \gamma_{1,t}(\pi_{t-1} - \pi_t^*) + \gamma_{2,t}ygap_{t-1} + \gamma_{3,t}r_{t-1} + \varepsilon_t^r, \quad (3)$$

where the original rule in Taylor (1993) is rewritten in terms of the real interest rate. Coefficients $\gamma_{1,t}$, $\gamma_{2,t}$, and $\gamma_{3,t}$, which denote the respective weights of the deviation of past inflation from the target, the output gap, and the autoregressive term, respectively, are expected to be positive.

The Beveridge-Nelson (1981) decomposition of output is as follows:

$$y_t = y_t^* + ygap_t. \quad (4)$$

Potential output and the natural interest rate are assumed to follow a local linear trend model such that

$$y_t^* = y_{t-1}^* + \mu_{t-1} + \varepsilon_t^{y^*} \quad (5)$$

$$r_t^* = r_{t-1}^* + \eta_{t-1} + \varepsilon_t^{r^*}, \quad (6)$$

where the two stochastic trends μ and η are defined as

$$\mu_t = \mu_{t-1} + \varepsilon_t^\mu \quad (7)$$

$$\eta_t = \eta_{t-1} + \varepsilon_t^\eta. \quad (8)$$

Obviously, $\varepsilon_t^{y^*}$, $\varepsilon_t^{r^*}$, ε_t^μ , and ε_t^η are the disturbance terms.

The model can be represented in the state-space form as follows:

$$x(t) = Fx(t-1) + Gu(t) + e_1(t) \quad (9)$$

$$y(t) = Hx(t) + e_2(t), \quad (10)$$

where $x(t)$ is the state vector, $y(t)$ is the observation vector, F is the transition matrix, H_k is the observation matrix, and G_k is a known matrix. $e_1(t)$ and $e_2(t)$ denote vectors of normally distributed iid shocks, which are assumed to be uncorrelated with each other and have covariance matrices R_1 and R_2 , respectively. Furthermore, $u(t)$ is the vector of exogenous variables.

The measurement equation that shows the evolution of the observed variables (inflation, output, and the real interest rate) can be described as a function of the state variables as follows:

$$\begin{bmatrix} \pi_t \\ y_t \\ r_t \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \pi_t \\ \pi_{t-1} \\ y_t^* \\ \mu_t \\ \rho_t \\ ygap_t \\ r_t \\ r_t^* \end{bmatrix}. \quad (11)$$

The transition equation can be expressed as

$$\begin{bmatrix} \pi_t \\ \pi_{t-1} \\ y_t^* \\ \mu_t \\ \rho_t \\ ygap_t \\ r_t \\ r_t^* \end{bmatrix} = \begin{bmatrix} \alpha_{1,t} & \alpha_{2,t} & 0 & 0 & 0 & \alpha_{3,t} & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \beta_{1,t} & \beta_{2,t} & 0 \\ \gamma_{1,t} & 0 & 0 & 0 & 0 & \gamma_{2,t} & \gamma_{3,t} & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \pi_{t-1} \\ \pi_{t-2} \\ y_{t-1}^* \\ \mu_{t-1} \\ \rho_{t-1} \\ ygap_{t-1} \\ r_{t-1} \\ r_{t-1}^* \end{bmatrix} + \begin{bmatrix} \alpha_{4,t} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \beta_{3,t} & 0 \\ 0 & -\gamma_{1,t} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} z_t \\ \pi_t^* \end{bmatrix} + \begin{bmatrix} \varepsilon_t^\pi \\ 0 \\ \varepsilon_t^{y^*} \\ \varepsilon_t^\mu \\ \varepsilon_t^\rho \\ \varepsilon_t^{ygap} \\ \varepsilon_t^r \\ \varepsilon_t^{r^*} \end{bmatrix}. \quad (12)$$

2.2 Alternative Model under Dynamic Homogeneity Condition

In order to analyze the robustness of the results to different model specifications, the dynamic homogeneity condition is imposed on the benchmark model specification. The dynamic homogeneity condition is the constraint that permanent changes in inflation should not affect output in the long run, thus implying neutrality. Nickell (1988) argues that “if the model does not possess this kind of neutrality, then unemployment can be shifted, even in the long run, simply by changing the level of inflation.”

Hence, imposing the dynamic homogeneity condition to the above system of equations implies that the existence of a trade-off between inflation and output is only limited to the short run (Greenslade, Pierse, and Saleheen 2003; Laubach and Williams 2003; Batini and Greenslade 2006). The restriction also implies that prices are determined by nominal factors such as wages and imported costs (Gómez and Julio 2000).

One way of imposing the dynamic homogeneity condition on a system of equations is to restrict the sum of the coefficients of the explanatory inflation terms in the Phillips-curve equation to be equal to unity. Another way to impose the same condition is to use differenced inflation terms in the Phillips-curve equation, and so the unity restriction is automatically satisfied (Fabiani and Mestre 2004).

Since the original Phillips-curve equation does not contain any differenced inflation terms, this paper sticks to the former approach. Hence, the dynamic homogeneity condition is imposed by restricting the sum of the lagged inflation terms in the Phillips-curve equation to be equal to unity (Bjørnland, Leitemo, and Maih 2007). Meanwhile, the state-space representation of the alternative model remains unchanged from the benchmark model specification.

3. Estimation Results

This section reports and discusses the estimation results. The model utilizes quarterly data on inflation, output, interest rate, and nominal exchange rate for the Turkish economy between 2002:Q1 and

2015:Q4.^{26,27} Inflation is measured as the logarithmic difference of the seasonally adjusted consumer price index.²⁸ Output is the seasonally adjusted real GDP series in logs with base year 1998. Real interest rate is the inflation-adjusted²⁹ overnight lending rates at the repo and reverse repo market of the Borsa Istanbul between 2002:Q1 and 2010:Q1, which is substituted for one-week repo rates and the average funding rate afterwards.³⁰ Exchange rate is the logarithmic difference of the USD/TRY spot rate. Target is the official

²⁶The data are publicly available and can be retrieved from the electronic data dissemination system of the CBRT at <https://evds2.tcmb.gov.tr>.

²⁷The time period covered in the analysis is crucial for the Turkish economy. In particular, after experiencing a major financial crisis in 2001, which led to the collapse of the IMF-backed exchange-rate-based disinflation program with an ultimate goal to switch to an inflation-targeting regime, the CBRT started to conduct an implicit inflation-targeting regime between 2002 and 2005. This was followed by the implementation of the strict inflation-targeting regime starting from 2006. In the last quarter of 2008, the CBRT had to face challenges originating from the global crisis that occurred in September 2008. Consequently, the CBRT adopted anti-crisis measures, which were later withdrawn starting from April 2010. Finally, as of end-2010, the CBRT has conducted a new monetary policy framework, which departed from strict inflation targeting by the inclusion of financial stability as a supplementary objective to its primary goal of maintaining price stability (Erçel 1999; Başçı, Özel, and Sarıkaya 2007; Kara 2008, 2013; Başçı and Kara 2011; IMF 2012).

²⁸Inflation is estimated using the consumer price index with base year 2003. The missing data for 2002 are computed by the consumer price index series with base year 1994.

²⁹The ex ante real interest rate is derived by adjusting nominal rates with the twelve-month-ahead inflation expectation series obtained from the CBRT's Survey of Expectations.

³⁰The CBRT's policy rate between 2002:Q1 and 2010:Q1 is the overnight lending rate at the repo and reverse repo market of the Borsa Istanbul. However, starting from May 2010, the CBRT has opted for a technical adjustment as part of the normalization process after the global crisis, where the one-week repo rate was used as the effective policy rate. With the adoption of the new monetary policy mix at end-2010, the one-week repo rate was officially announced as the policy rate. However, an active liquidity-management policy was also implemented, which adjusted market rates without changing the policy rate. In fact, the CBRT started to impose additional monetary tightening and continued to do so occasionally until January 2014. Hence, in order to capture this switch, the policy rate in the analysis is replaced by the one-week repo rate as of 2010:Q2, and to account for the additional monetary tightening, it is replaced by the average funding rate as of 2012:Q1. This corresponds to the effective rate at which the CBRT injects liquidity (Başçı and Kara 2011; CBRT 2012, 2014; IMF 2012; Küçükşaracı and Özel 2012; Alper, Kara, and Yörükoğlu 2013a; Kara 2013; Ermişoğlu et al. 2014).

inflation target set by the CBRT. Seasonal adjustment is handled via TRAMO/SEATS (Gómez and Maravall 1996). The initial values are set according to Chan and Hsiao (2011).³¹

3.1 Benchmark Model Results

Estimation results of the benchmark model are presented in figure 1. Accordingly, model-consistent estimates for the natural rate, real interest rate, inflation, potential output, output, and output gap are illustrated over the analyzed period. In addition, actual values for the real interest rate, output, and inflation are also depicted in order to assess the plausibility of the estimation results. The analysis provides a graphical breakdown of the CBRT's regime switches, which are explained in detail in footnote 28. In particular, the monetary policy conduct is categorized as implicit inflation targeting, strict inflation targeting, global crisis, and new monetary policy mix for the periods 2002:Q1–2005:Q4, 2006:Q1–2008:Q4, 2009:Q1–2010:Q4, and 2011:Q1–2015:Q4, respectively.

Against this background, figure 1 indicates that the model-consistent estimate for the natural interest rate mostly follows a downward path, which is in tandem with the actual real interest rate. In addition, the real interest rate estimate is reasonable given the actual real interest rate. Meanwhile, the estimated inflation rate is plausible with respect to the actual inflation rate during the analyzed period. Figure 1 also shows the model-consistent estimate for potential output and output gap besides output, which can simply be computed by equation (4).

A closer scrutiny reveals that the actual real interest rate and the estimated natural interest rate are mostly parallel despite occasional divergences. In particular, the natural interest rate estimate is above the real interest rate until 2004:Q1, while the model-consistent estimate for the real interest rate is also generally above the actual real interest rate during that period. Moreover, the inflation estimate is slightly higher than the actual inflation rate in the same period.

³¹The state-space representation for EKF is given in the appendix. Accordingly, it should be noted that the EKF needs predefined $P_{0|0}$, Q , R , and $\hat{x}_{0|0}$ for initialization. It is acceptable to assign $P_{0|0}$ arbitrarily; however, the values must be large enough to allow good tracking of the parameters. If the states are measured, $\hat{x}_{0|0}$ can be specified by taking the average of the first few data points.

Figure 1. Benchmark Model Results

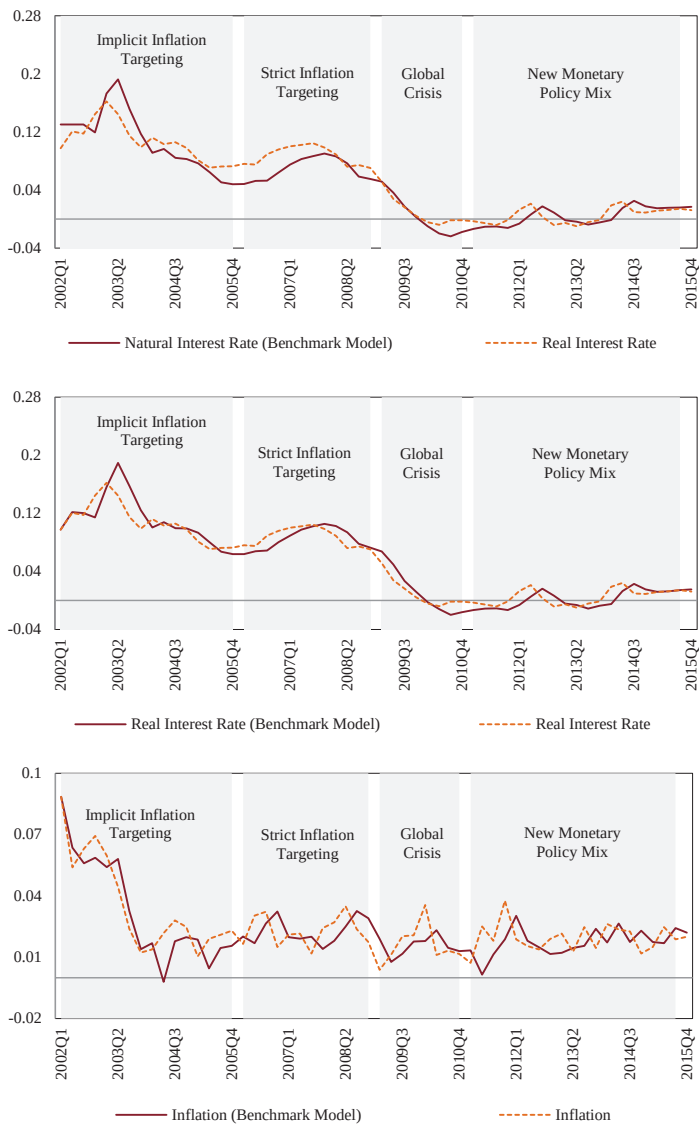
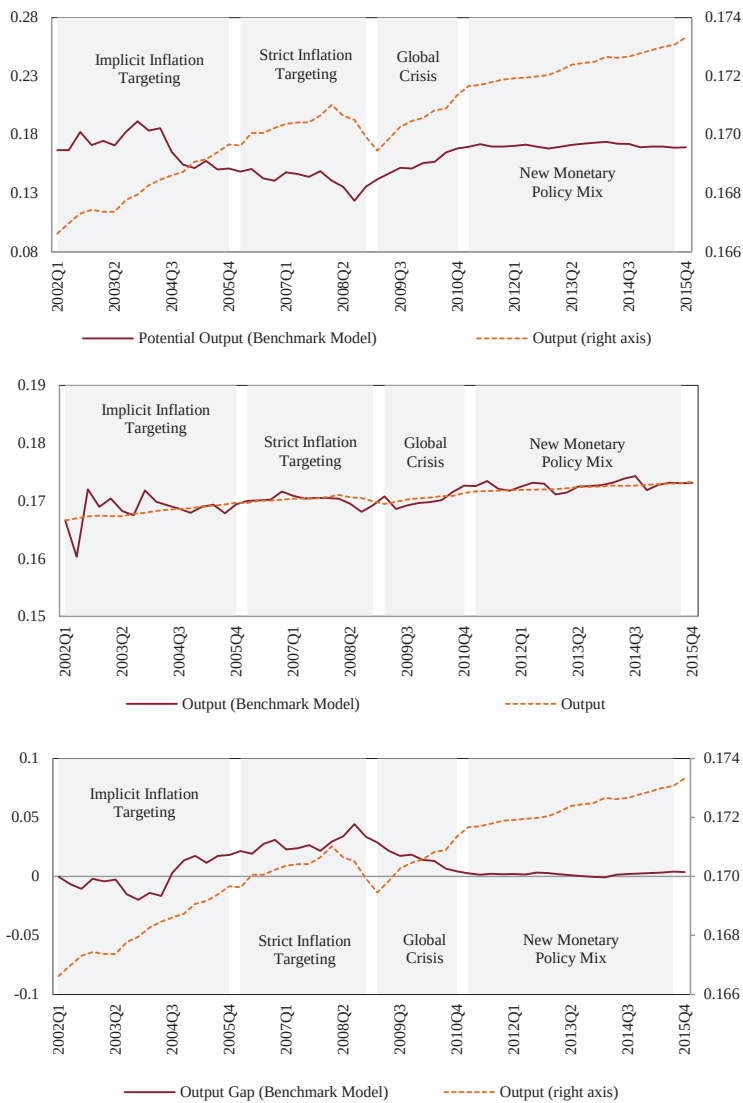


Figure 1. (Continued)



Hence, the model predicts a higher real interest rate and a slightly higher inflation rate, which may indicate that the policy rates were cut more aggressively and inflation fell more sharply than envisioned by the model.^{32,33}

As of the first quarter of 2004, the benchmark model estimates the natural interest rate to be below the actual real interest rate. The gap between the two series gets wider from 2005:Q1 onwards when the natural interest rate estimate sets off for a rapid decline, whereas the actual real interest rate remains relatively unchanged during the same period. Starting from the first quarter of 2006, the natural interest rate starts to creep up, while the actual real interest rate also begins to increase.

In the meantime, the estimated real interest rate follows a slightly declining path close to the actual real interest rate between 2004:Q1 and 2004:Q4. During a brief period from 2004:Q4 to 2005:Q3, the real interest rate is estimated to be marginally higher than the actual real interest rate, whereas the real interest rate is expected to lag behind the actual real interest rate as of 2005:Q3. Hence, the model predicts the real interest rate and the inflation rate to be lower than their corresponding actual values, which indicates that there was room for an additional policy rate cut. This is especially valid immediately before and at the onset of the strict inflation-targeting regime period.³⁴

³²The policy rate was reduced from 57 percent in February 2002 to 26 percent in October 2003. The policy rate reduction was more accelerated during April–October 2003, with an initial rate cut of 300 basis points in April 2003, which was followed by regular cuts, pulling the policy rate to 26 percent in October 2003 (<http://www.tcmb.gov.tr/wps/wcm/connect/tcmb+en/tcmb+en/main+page+site+area/cbrt+policy+rates/cbrt+interest+rates>).

³³Following the crisis in 2001, the CBRT acted decisively to combat inflation, which had been elevated for a long time, especially during the 1990s. Accordingly, actual inflation was recorded as 29.7 and 18.4 percent, undershooting the year-end inflation target set at 35 and 20 percent in 2002 and 2003, respectively. (<http://www.tcmb.gov.tr/wps/wcm/connect/tcmb+en/tcmb+en/main+menu/monetary+policy/price+stability/inflation+targets>).

³⁴After delivering a policy rate cut of a total of 350 basis points in 2005, the CBRT was reluctant to reduce policy rates between January and March 2006, given the absence of signs for an improvement in the medium-term inflation outlook (CBRT 2006a, 2006b, 2006c). Consequently, the CBRT delivered a moderate policy rate cut of only 25 basis points in April 2006 (CBRT 2006d). On the other hand, the unforeseen financial turbulence driven by international conditions in

Yet, the story changes starting from the last quarter of 2007, as the estimated real interest rate series stays above the actual real interest rate, which suggests that a more preemptive monetary policy could have been implemented against the impending global crisis.³⁵ This is also reflected in the difference between the natural interest rate and the actual real interest rate, as the gap almost disappears in the first half of 2008 against the relatively sharper fall in the actual real interest rate. Yet, the gap rewidens as the natural interest rate declines rapidly in the second half of 2008, whereas the real interest rate rises during the same period. On the other hand, from 2009:Q1 to 2009:Q4, the natural interest rate decreases remarkably, while the actual real interest rate also drops significantly.

The radical decrease in the actual real interest rate may obviously be due to the adoption of extraordinary expansionary measures against the adverse effects of the global crisis.³⁶ Meanwhile, the fall in the natural interest rate may be the result of the global downturn that was experienced during that period. In particular, this downturn might have pulled down the natural interest rate amid changes in global demand and supply, which unfavorably affect the foreign demand for domestic goods. As a matter of fact, the natural interest rate falls even below zero in the first quarter of 2010 due to lingering weaknesses in the global economy, which had further adverse effects on the domestic economy. In the meantime, the actual real interest rate hits negative values in 2010:Q1. Despite the CBRT's exit from anti-crisis easing measures in the second quarter of 2010, the actual real interest rate remains below zero.³⁷

May 2006 necessitated an aggressive policy rate hike. Accordingly, the CBRT raised the policy rates by a total of 425 basis points between June 8 and July 21, 2006 (CBRT 2006e, 2006f, 2006g).

³⁵Following the major rate hike in July 2006, which pushed the interest rates up to 17.50 percent, policy rates were reduced gradually to 15.25 percent until February 2008. However, starting from May 2008, policy rates were raised with three consecutive hikes to 16.75 percent in July 2008 against the blurry outlook in financial markets, while further rate hikes were also signaled (CBRT 2008).

³⁶From October 2008 to end-2009, policy rates were cut aggressively from 16.75 percent to 6.50 percent.

³⁷The CBRT announced its exit strategy regarding the withdrawal of anti-crisis measures and normalization of the monetary policy on April 14, 2010 (CBRT 2010).

After reaching the bottom in the third quarter of 2010, the natural interest rate starts to climb up slightly. However, the benchmark model still envisions a negative natural interest rate. In fact, the natural rate is estimated to be below zero until the end of the first quarter of 2012. This may be attributed to the euro-zone debt crisis, which had unfavorable effects on the Turkish economy.³⁸ In the meantime, the real interest rate estimate is also negative in the same period and lower than the actual rate, implying that the monetary policy should have been looser.³⁹ Meanwhile, the inflation estimate rises sharply yet lags behind the actual inflation figures.

Starting from the last quarter of 2011, which is marked by the launch of occasional implementation of additional monetary tightening, the actual real interest rate starts to rise rapidly above

³⁸The sovereign debt problems in some euro-zone countries led to an escalation of global risk aversion, thus resulting in sudden outflows of capital from emerging market economies, including Turkey. The so-called euro-zone debt crisis was felt heavily from August 2011 to June 2012, causing unfavorable risk perception towards Turkey, which also led to elevated volatility and deteriorated current account balance (Akçelik et al. 2013).

³⁹The CBRT started to conduct the new monetary policy mix at end-2010 in an environment of strong capital inflows and an overvalued exchange rate. Hence, the monetary policy conduct was mostly oriented towards containing the adverse effects of these massive capital inflows on financial stability. This was sought to be achieved via lower overnight borrowing rates and a wider interest rate corridor along with tightened required reserve ratios, which are differentiated by maturity. In addition, the CBRT held regular FX purchase auctions in return for Turkish lira liquidity injection where the pre-announced amounts would be set according to the perceived strength of the capital inflows. However, these measures led to a significant increase in liquidity, which was fed into credit growth, widening the current account deficit and elevating inflationary pressures. Besides, the deteriorated global risk appetite due to the euro-zone debt crisis caused reversal in capital flows. Against this background, the CBRT started to hold FX sale auctions in order to provide FX liquidity in return for TL liquidity, and also reduced the volumes of quantity auctions. Furthermore, the interest rate corridor was widened upwards, while the reserve requirement ratio for TL liabilities was reduced. In the meantime, overnight interest rates were adjusted via day-to-day liquidity policy in response to the course of economic and financial developments without changing the policy rate. Against this tightening bias, the CBRT preferred to deliver the necessary tightening via episodes of additional monetary tightening, a tool that has occasionally been used as of end-2011 in order to prevent undesired exchange rate movements from deteriorating the inflation outlook through pass-through and expectations (IMF 2012; Akçelik et al. 2013).

zero.⁴⁰ Meanwhile, the natural interest rate increases but still remains in the negative territory until the second quarter of 2012. However, the increase is rather short-lived and the natural interest rate continues to be negative in the first quarter of 2013. In fact, the natural interest rate remains negative around zero for a considerably long period of time until the end of the first quarter of 2014. However, as of the second quarter of 2014, the natural interest rate starts to rise and remains unchanged above zero since the last quarter of 2014.

In the meantime, the real interest rate estimate is higher than the actual interest rate during the implementation of additional monetary tightening. However, the benchmark model predicts the real interest rate to be negative and close to the actual real interest rate during the first half of 2013, whereas in the second half, the model predicts a lower-than-actual real interest rate, which is also negative.⁴¹ Even though the actual interest rate turns positive in the first quarter of 2014, the real interest rate estimate is still negative during this period. However, following a parallel move with the actual interest rate, the estimate for the real interest rate also turns positive in the second quarter of 2014.⁴² After a period of small deviation between the two series during the second half of 2014, the real interest rate estimate almost converges with the actual real interest rate as of the beginning of 2015.

⁴⁰In the last quarter of 2011, monetary policy had been oriented towards containing the upside risks to inflation due to weakening of the domestic currency driven by worsening risk appetite amid the euro-zone debt crisis. In response, the CBRT delivered a sizable lending rate hike in October 2011 and also implemented additional monetary tightening by widening the interest rate corridor upwards and reducing the amount of funding provided by the weekly repo auctions (Başçı and Kara 2011).

⁴¹The decisive steps taken to resolve the euro-zone debt crisis resulted in lower prospects for a sudden stop in capital flows in early 2012. Meanwhile, global risk appetite improved considerably. Hence, the CBRT opted for a gradual monetary easing and provided ample liquidity to the market in the third quarter of 2012. Accordingly, real interest rates fell significantly in early 2013 and reached negative values (Kara 2013).

⁴²Upon the Fed's taper signal in May 2013, global risk appetite started to decline, which led to sudden outflows of capital from emerging economies, including Turkey. The elevated uncertainty regarding the Fed's exit from quantitative easing resulted in an excessive depreciation of the Turkish lira and volatility in financial markets. This caused the CBRT to adopt a tight liquidity policy and to raise the upper band of the interest rate corridor in July 2013, which was followed by a front-loaded monetary tightening in August 2013. Consequently, both nominal and real interest rates increased notably (CBRT 2014, 2015b).

Meanwhile, the benchmark model produces an output series, which is slightly more fluctuating than the actual output in general. In particular, the model envisions higher yet volatile output during the early phases of the implicit inflation-targeting regime. However, the model predicts lower output at the onset of the global crisis, which is expected to recover strongly afterwards. The model envisages somewhat higher, but slightly more volatile output during the new monetary policy mix implementation.

As for the potential output, the benchmark model's estimate is plausible, as the series is able to capture the major turning points of the economy. To be specific, the estimated potential output is on a mild upward track during the early phases of the implicit inflation-targeting regime. However, the series starts to follow a downward trend until the beginning of the global crisis, which is succeeded by a sharp decline. The potential output recovers quickly after the global crisis, and it settles on a plateau as of 2010. The potential output estimate is considered to be successful, as the series parallels the actual output especially in portraying the sharp decline during the global crisis and the subsequent strong recovery. The estimated potential output series is also able to depict the modest trend of growth in the economy during the 2010–15 period.

As for the output gap, in tandem with the upward course of the potential output series in the early phases of the implicit inflation-targeting regime, the estimated output gap series is negative, hinting at the absence of demand-side inflationary pressures. Parallel to the downtrend of the potential output series until the onset of the global crisis, the estimated output gap takes on positive values, implying that inflation has been exposed to demand-side pressures. The relatively higher increase in potential output than the actual output in the aftermath of the global crisis is reflected as a narrowing output gap, which indicates that the demand-side inflationary pressures have alleviated in this period. The flat course of the potential output and the moderate uptrend in output as of 2010 cause the output gap to close in the same period. This may be attributed to the implementation of tight monetary policy during this episode.⁴³

⁴³It should be noted that this paper focuses on estimating the natural interest rate. Hence, the measurement of potential output and the output gap may not be as sophisticated as those in other models, which only compute these series

Finally, the benchmark model produces an inflation series, which moves in line with the actual inflation. Both series follow a similar course, except for the last quarter of 2002 and the second quarter of 2004 when the benchmark model predicts a fall in inflation in contrast to the rise in actual inflation. Similarly, in the early phases of the global crisis period, the benchmark model envisions that the estimated inflation series increases at a relatively milder pace than the actual inflation. The benchmark model also envisages a lower and less volatile inflation during the implementation of the new monetary policy mix.

3.2 Alternative Model Results

In order to check the robustness of the model specification, the dynamic homogeneity constraint is imposed as an alternative to the benchmark model. The estimation results that are presented in figure 2 show that the restriction leaves the estimated natural interest rate series almost unchanged from the benchmark model. The same conclusion can be drawn for the real interest rate estimate.

On the other hand, imposing the dynamic homogeneity constraint results in relatively higher potential output and a lower output gap than estimated by the benchmark model. However, the constraint seems to have no major impact on these two estimates during the implementation of the new monetary policy mix. Meanwhile, the output produced by the alternative model is almost equal to the benchmark model's estimate, except for a brief period in 2003 during the strict inflation-targeting regime where the alternative model forecasts a strong fall. During the same period, the alternative model predicts higher inflation than envisioned by the benchmark model. Otherwise, the inflation estimate of the alternative model closely follows that of the benchmark model.

such as Özbek and Özlale (2005), Kara et al. (2007), Alp, Ögünç, and Sarıkaya (2012), and Erdoğan-Coşar, Kösem, and Sarıkaya (2012). Also, the estimate for the output gap may not necessarily follow the official output gap forecasts, which are produced for the latest twelve-month and the upcoming three-year period. Yet, the output gap estimate during the implementation of the new monetary policy mix is more successful, as it is consistent with IMF (2013, 2014).

Figure 2. Alternative Model Results

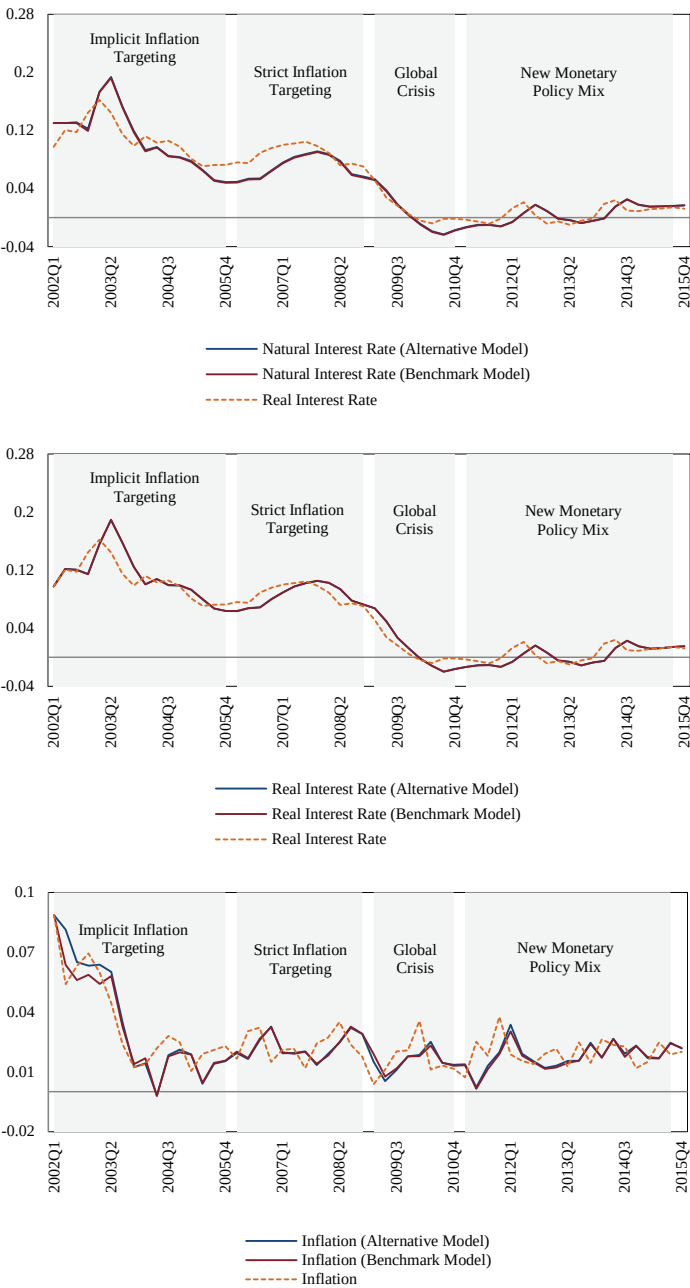
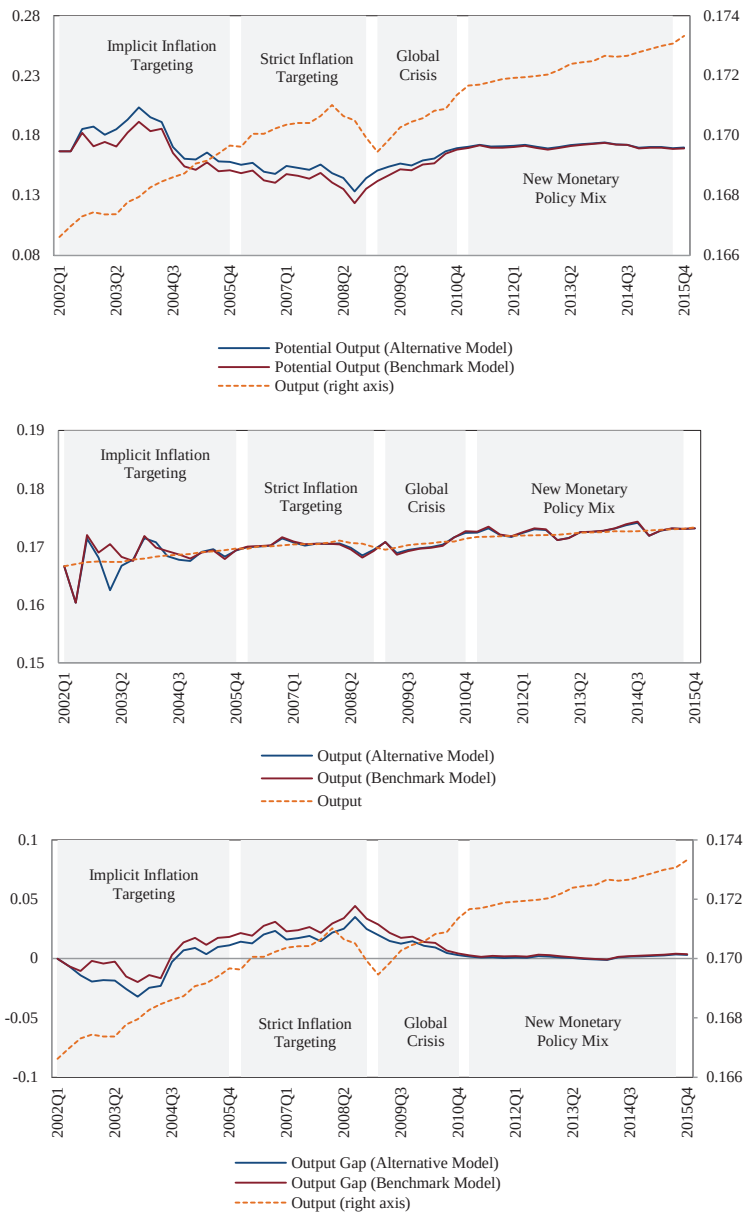


Figure 2. (Continued)



3.3 *Smoothing Algorithm Results*

As an additional step to check the robustness of the model specification, the Rauch-Tung-Striebel (RTS) smoothing algorithm is applied. The RTS is a two-pass smoother, which consists of a forward-pass EKF with a backward recursion smoother.⁴⁴

Figure 3 presents the estimation results of the application of the RTS algorithm to the benchmark model. As expected, the algorithm produces a smoother natural interest rate estimate than the benchmark model. In general, the new estimate is observed to be lower than that of the benchmark model until end-2009. However, starting from 2010, the algorithm produces a smoother series around zero, yet this fails to capture the negative zone experience as predicted by the benchmark model. The algorithm also smooths out the subsequent peak observed during the third quarter of 2012, which is followed by a decline. The smoothed series is close to the benchmark model's estimate as of 2015, which is marked by a period of relatively flat natural interest rate above zero.

As for the real interest rate, the RTS algorithm improves the results, as the smoothed series is closer to the actual real interest rate than the benchmark model's estimate. This observation is also valid for inflation, as applying the RTS algorithm results in smoother inflation series, which better reflects the actual inflation dynamics.

Meanwhile, the RTS algorithm causes virtually no significant difference in the potential output estimate as of end-2009 onwards. This corresponds to the global crisis period and the implementation of the new monetary policy mix. Otherwise, the smoothed series implies a lower potential output, which is slightly less volatile. Consequently, the output gap estimate under the smoothing algorithm is similar to that of the benchmark model during the global crisis period and the implementation of the new monetary policy mix. However, in other periods, the RTS algorithm implies a slightly higher output gap with relatively lower volatility. Meanwhile, the smoothed output series is more successful in describing the dynamics of the actual output.

⁴⁴For further details on the RTS smoother, see Rauch, Striebel, and Tung (1965).

Figure 3. Smoothing Algorithm Results

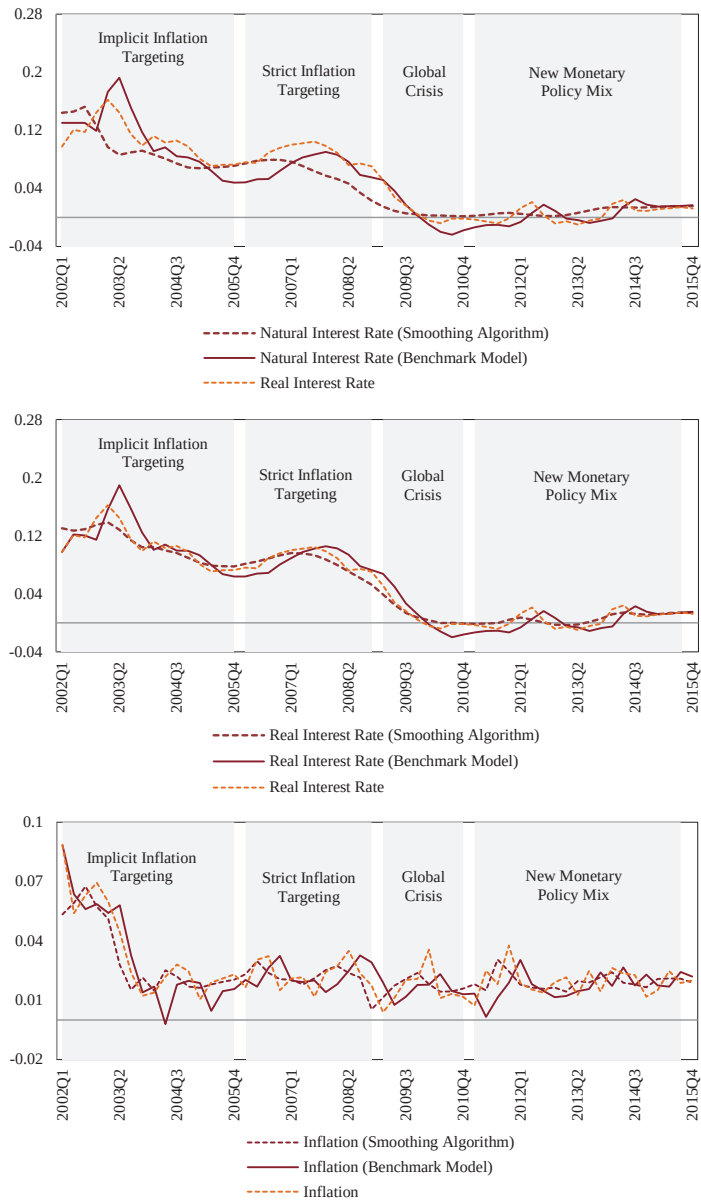
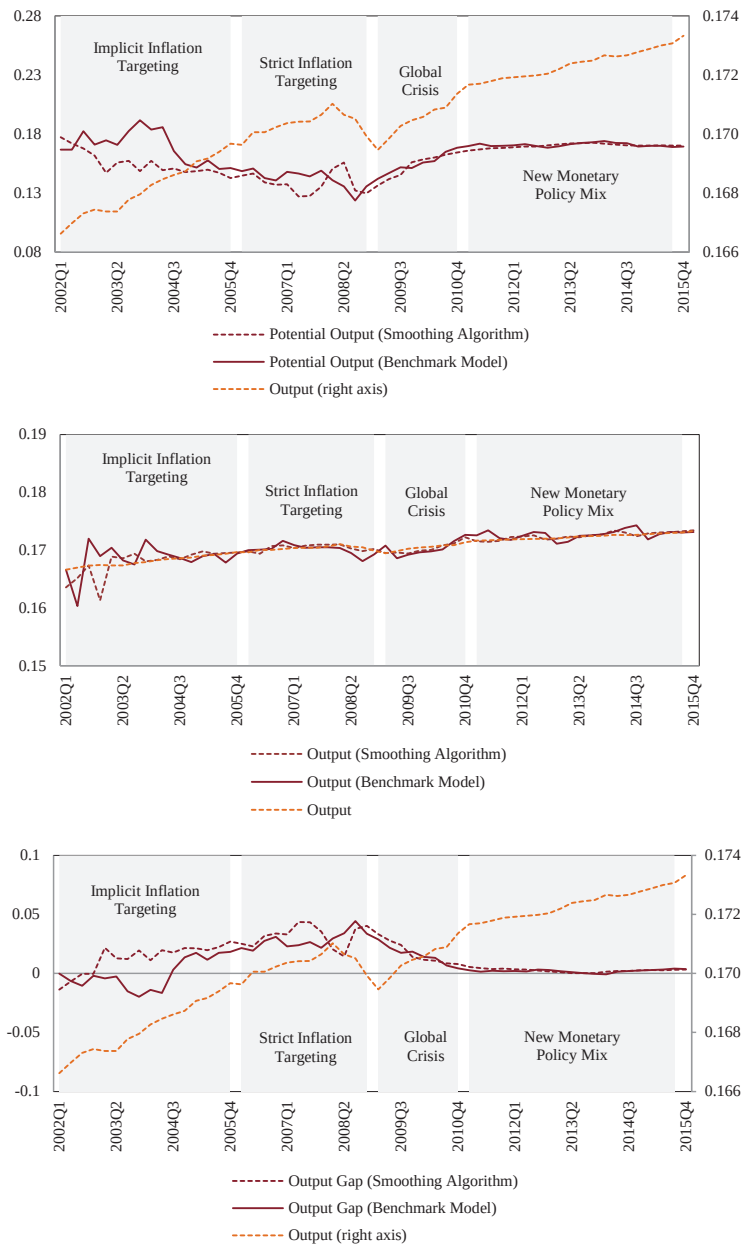


Figure 3. (Continued)



3.4 *Alternative Measures of Inflation Target*

As a final step in the improvement of the results, the inflation target is replaced with alternative target measures. Accordingly, the official inflation target is replaced with the twelve-month-ahead expected inflation series obtained from the CBRT's Survey of Expectations.⁴⁵

The same exercise is repeated with the year-end inflation expectation. Using alternative target measures may enable one to see whether the model is sensitive to periods of divergences of expectations from the official inflation target.⁴⁶ Accordingly, figure 4 shows that the estimation results differ only marginally. In particular, the year-end inflation expectation produces a slightly lower natural interest rate during the implicit inflation-targeting regime, while natural interest rate estimates are similar otherwise.

The same finding is observed for the real interest rate. More specifically, the real interest rate estimate is lower during the implementation of the implicit inflation-targeting regime when the official inflation target is replaced with the year-end inflation target. However, real interest rate estimates are similar under all specifications in other periods.

3.5 *Time-Varying Parameters*

Figure 5 presents the time-varying parameters produced under the benchmark model and the alternative model as well as the smoothing algorithm. Accordingly, α_1 , the coefficient of the lagged inflation

⁴⁵The CBRT has been conducting a bi-monthly survey since August 2001 in order to assess expectations of selected professionals in the finance and corporate sector on major macroeconomic indicators. For details, see <http://www.tcmb.gov.tr/wps/wcm/connect/tcmb+en/tcmb+en/main+menu/statistics/tendency+surveys/survey+of+expectations>.

⁴⁶The inflation target is determined jointly by the CBRT and the government as stipulated by the Central Bank Law No. 1211. The target was set as point targets during the implicit inflation-targeting regime between 2002 and 2005. However, since 2006, the target has been set as a midpoint target with a 2 percent uncertainty band. The CBRT succeeded in undershooting the inflation target for four consecutive years during 2002–05. However, since 2006, the target has been breached every year, except in 2009 and 2010, when the target was revised to 7.5 and 6.5 percent, respectively, from the previously set 4 percent. For details, see <http://www.tcmb.gov.tr/wps/scm/connect/tcmb+en/tcmb+en/main+menu/monetary+policy/price+stability/inflation+targets>.

Figure 4. Alternative Measures of Inflation Target

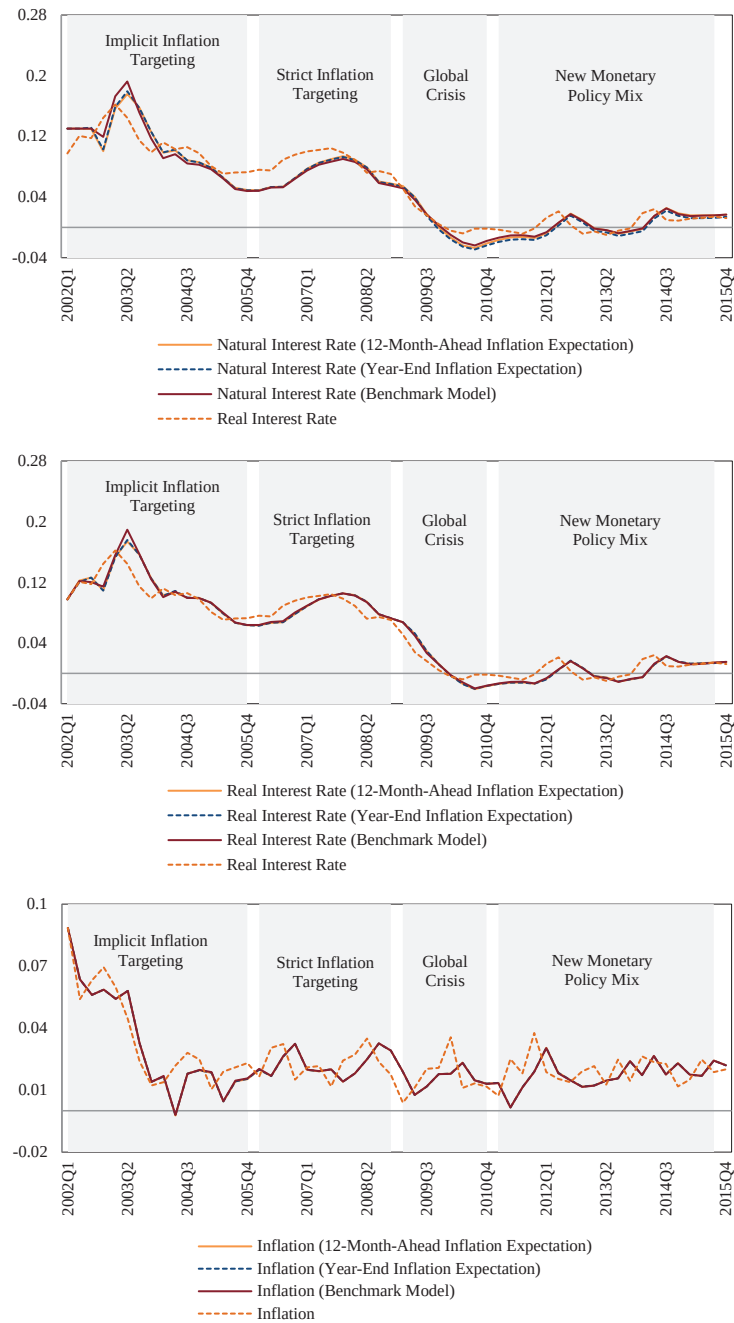


Figure 4. (Continued)

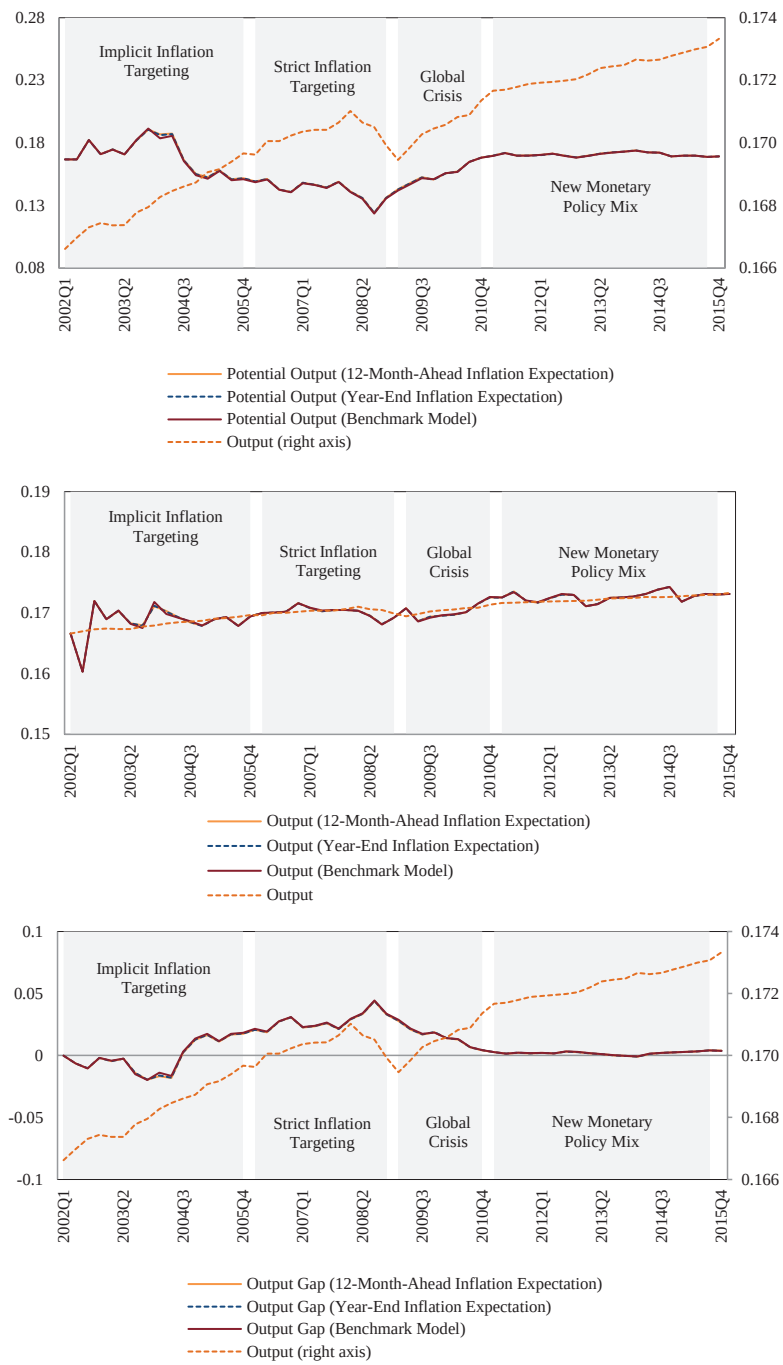
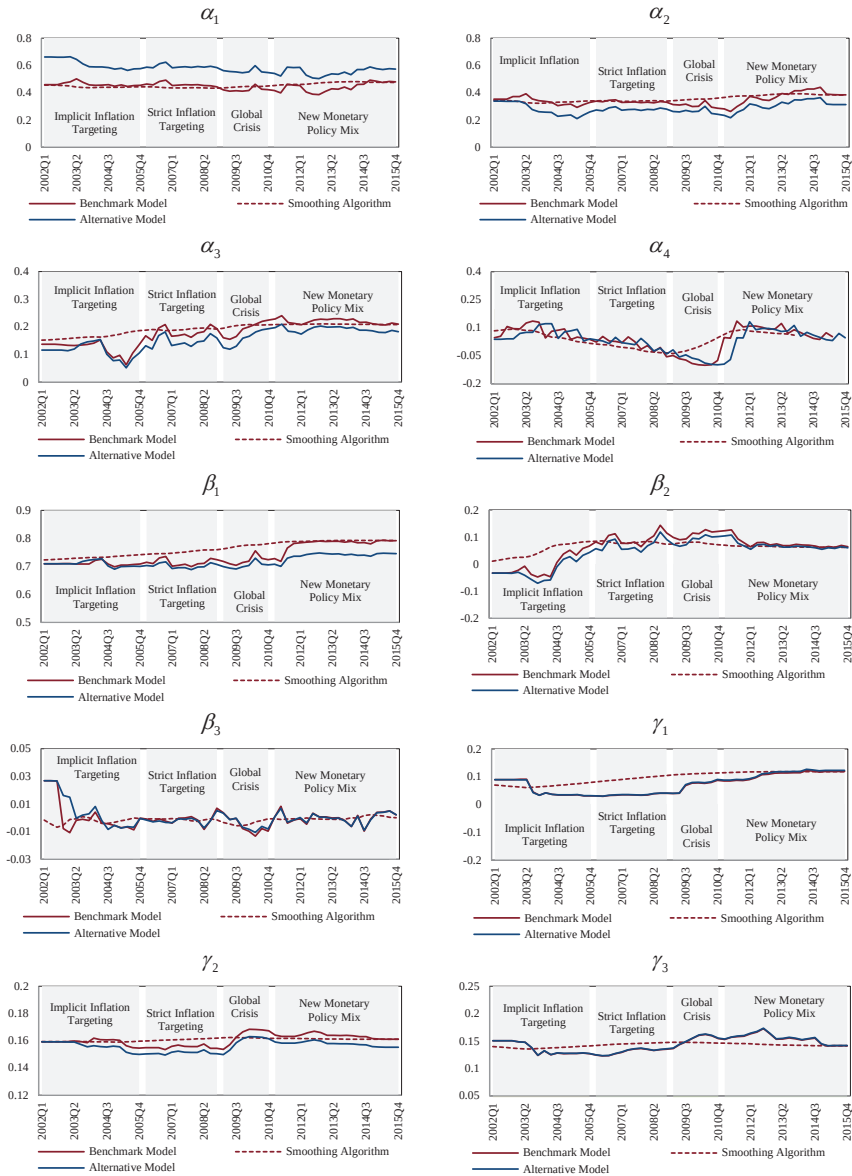


Figure 5. Time-Varying Parameters



term in the Phillips curve, shows that the inflation persistence is higher but gradually declining in the alternative model until the adoption of the new monetary policy mix. Meanwhile, inflation persistence is lower and relatively constant in the benchmark model and under the smoothing algorithm. The adoption of the new monetary policy mix reduces the persistence in the benchmark model as well as in the alternative model. However, inflation persistence increases in both models as of end-2012, while it remains unchanged under the smoothing algorithm.

Meanwhile, α_2 , which denotes the coefficient of π_{t-2} , is relatively higher in the benchmark model compared with the alternative model. Yet, the coefficients in both models follow a similar course, which is mildly downwards during the implicit inflation-targeting regime but relatively stable in the strict inflation-targeting period.

The coefficient in both models declines during the global crisis. However, with the adoption of the new monetary policy mix, the coefficient assumes a significantly upward course. Yet, recently, α_2 is relatively stable in both models. On the other hand, α_2 is steady but relatively higher at the end of the analyzed period compared with the beginning of the implicit inflation-targeting regime under the smoothing algorithm.

The analysis shows that α_3 , the coefficient of the output gap in the Phillips curve that captures the demand-side inflationary pressures, is comparatively higher in the benchmark model than the alternative model. The coefficient increases at a fluctuating course in both specifications until the end of the global crisis, whereas it follows a mild upward trend during the same period under the smoothing algorithm. The coefficient is steady in all specifications during the implementation of the new monetary policy mix.

The results indicate that α_4 , the coefficient of the exchange rate in the Phillips-curve equation that signifies supply-side inflationary pressures, declines in all specifications until the end of the global crisis. However, the downward course followed by the coefficient is slightly volatile in both the benchmark model and the alternative model. The coefficient displays a sharp rise with the adoption of the new monetary policy mix, yet resettles on a downward course as of the beginning of 2012 in all models.

The feedback parameter β_1 , which is the coefficient of the lagged output gap in the IS curve, is almost constant until the end of the

global crisis. On the other hand, the smoothing algorithm implies a steady upward course for β_1 during the same period. Hence, the coefficient produced by the smoothing algorithm is relatively higher compared with other specifications, while the alternative model envisions a slightly lower coefficient compared with the benchmark model.

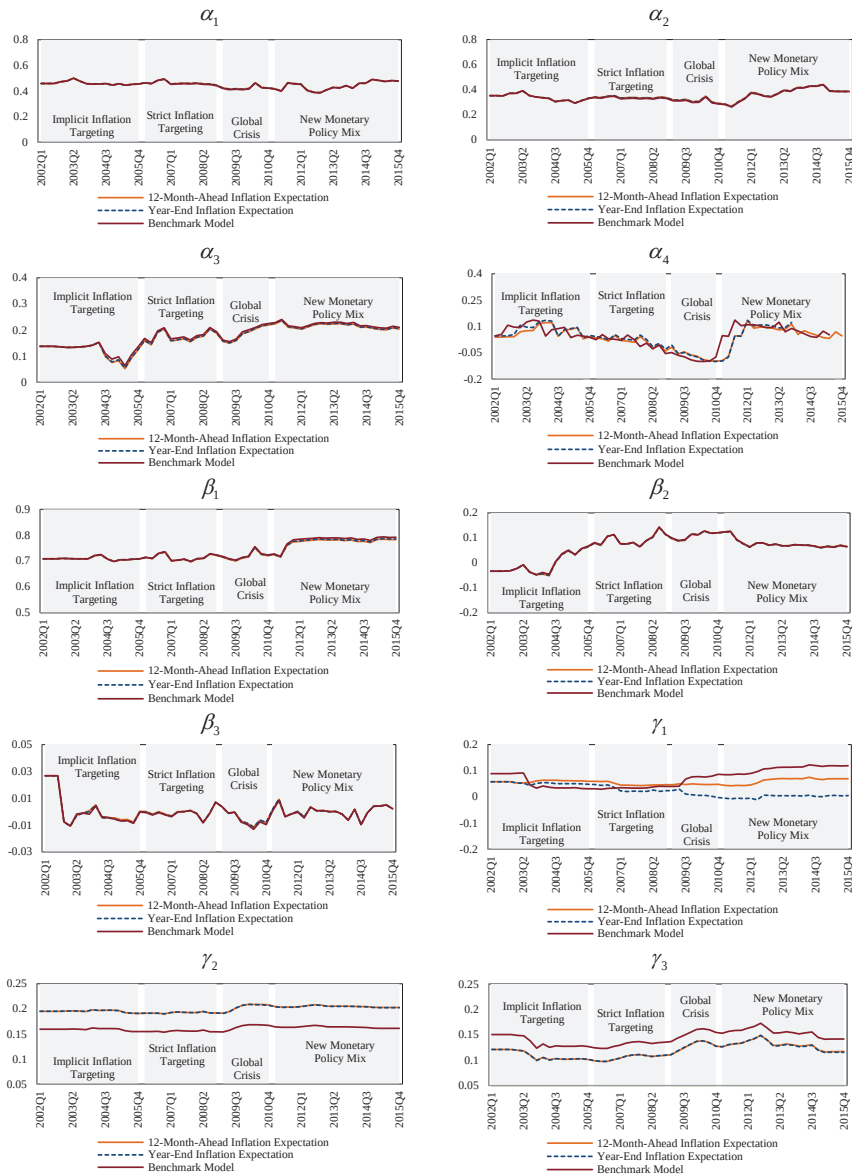
The adoption of the new monetary policy mix causes the coefficient to display a rise in both the benchmark model and the alternative model, yet this is more evident for the former. However, following this initial jump, the coefficient stabilizes in both specifications as of end-2011. In the meantime, the coefficient is stable under the smoothing algorithm.

The coefficient of the real interest rate in the IS curve that is denoted by β_2 rises in the benchmark model and also in the alternative model until the end of the global crisis. The coefficient is relatively higher in the benchmark model than in the alternative model. The adoption of the new monetary policy mix causes the coefficient to register a sharp decline in both models, while the coefficient remains constant as of the beginning of 2012. Meanwhile, the coefficient produced under the smoothing algorithm follows an upward course during the implementation of the implicit inflation-targeting regime but settles on a steady path afterwards.

As for the coefficient of the exchange rate in the IS curve that is denoted by β_3 , except for the decline experienced during the implicit inflation-targeting regime, the coefficient is volatile but relatively constant in both the benchmark model and the alternative model. On the other hand, the coefficient is noticeably less fluctuating under the smoothing algorithm.

Regarding the parameters of the Taylor rule, the coefficient for the deviation of the lagged inflation term from the inflation target, which is represented by γ_1 , is almost equal in both the benchmark model and the alternative model, whereas it is higher under the smoothing algorithm except for a brief period at the start of the implicit inflation-targeting regime. After a decline in the third quarter of 2003, both models predict the coefficient to be stable until the global crisis, while the smoothing algorithm foresees a mildly upward course during the same period. On the other hand, the global crisis instigates a steady rise in γ_1 , which is followed by a horizontal course as of the third quarter of 2012 in both models. However, the

Figure 6. Time-Varying Parameters under Alternative Measures of Inflation Target



coefficient is flat under the smoothing algorithm during the same period.

The coefficient of the output gap in the Taylor rule that is denoted by γ_2 is higher in the benchmark model than that produced by the alternative model. The coefficient declines marginally in both models until the global crisis. However, with the onset of the global crisis, the coefficient rises sharply and settles at a higher plateau afterwards. Meanwhile, the smoothing algorithm produces an almost constant coefficient throughout the analyzed period.

Finally, the coefficient of the lagged interest rate term in the Taylor rule, which is represented by γ_3 , is almost similar in the benchmark and the alternative model specifications. Following a drop in the second quarter of 2003, the coefficient remains stable in both models until the global crisis. However, the coefficient rises slightly during the global crisis and also with the adoption of the new monetary policy mix. The coefficient declines as of the third quarter of 2012. Meanwhile, the coefficient is constant under the smoothing algorithm throughout the analyzed period.

Figure 6 displays the time-varying parameters of the benchmark model in comparison with the alternative inflation target measures. Accordingly, the Phillips-curve and the IS-curve coefficients remain unchanged, while the parameters of the Taylor rule differ considerably with alternative target measures. In particular, γ_1 declines quite notably with the global crisis, with the year-end inflation expectations producing the lowest coefficient. Meanwhile, γ_2 increases significantly, whereas γ_3 decreases remarkably under alternative inflation target measures.

4. Conclusion

The natural interest rate is a vital concept in representing the monetary policy stance. By definition, the natural interest rate is the real interest rate level, which is consistent with stable output and inflation. Yet, attempting to model natural interest rate in an emerging economy, like Turkey, where inflation has not been stable is obviously a problem. This problem gets even worse considering the fact that the Turkish economy is also characterized by highly volatile output and rapidly changing macroeconomic dynamics. Apparently,

conventional methods for estimating natural rates may fail to capture this volatility and produce too-smooth trends.

This paper takes the above discussion as its starting point and attempts to estimate the natural interest rate for the Turkish economy. The empirical framework is based on a system of equations, which is in the spirit of Laubach and Williams (2003). However, in view of the highly volatile nature of the Turkish economy, this study improves this methodology by introducing time-varying parameters into the model. Since time-varying parameters and state variables are estimated simultaneously, the model presents non-linearity that can be handled via EKF.

EKF is a useful algorithm that can successfully control the issue of non-linearity introduced by the requirement to simultaneously estimate time-varying parameters and solve the state problem. Moreover, the use of EKF avoids the problem of finding a “too-smooth trend” without having to resort to the strong restrictions that are imposed on the parameters in previous studies.

The results reveal that the estimated series and the parameters are fairly reasonable. The natural interest rate moves in tandem with the actual real interest rate, yet the series is also sensitive to major shocks, which are believed to have an impact on the natural interest rate. In particular, the global crisis is assessed to be a significant shock, which has changed the dynamics of the economy. The period after the global crisis is dominated by the post-crisis spillovers from advanced economies to emerging markets, which require the implementation of unconventional policies and extraordinary measures in both country groups. Yet, this causes policy rates to be stuck at the zero lower bound and to decline even into the negative zone. The underlying reasons for these may obviously have important implications for the natural interest rate as well.

As for the Turkish economy, even though the monetary policy conduct after 2010 entails the joint use of multiple tools, financial market players continue to be curious about the level of the short-term policy rates by keeping a more-than-ever watchful eye on the policy rate announcements of the CBRT in this period. This is mainly due to the fact that of all the monetary policy instruments that are in the CBRT's toolkit, the short-term interest rate is the simplest one to be publicly understood and communicated.

Therefore, knowing the true level of the natural interest rate is important, as it provides information regarding how far the real interest rate is from this natural rate.

Meanwhile, the assessment of the model shows that the estimated real interest rate and inflation are plausible as they move parallel to their respective originals. Moreover, the same observation is true for the output and also for the potential output, which captures the major turning points of the actual output without following a too-smooth trend. The estimated output gap is also able to represent the stance of the demand-side inflationary pressures in the economy. These observations are valid not only for the benchmark but also for the alternative model under the dynamic homogeneity constraint. Also, the smoothing algorithm and alternative target measures leave the results virtually unchanged. Hence, one can conclude that the models are robust and correctly specified.

On the other hand, it should be noted that the estimations are based on aggregate data on output and inflation. Clearly, aggregate demand and inflation may have different dynamics by subcategories. In particular, the degree of persistence and the sensitivity of inflation to the exchange rate and the output gap may change if disaggregated data is used for inflation and output. This affects the derivation of the natural interest rate series.⁴⁷

In conclusion, this paper serves useful for further research on measuring the natural interest rate in Turkey, which is a significant yet underexplored issue. In addition, the study contributes to the existing literature by jointly estimating the natural interest rate and its time-varying relationship with macroeconomic variables. Also, this multivariate framework produces unobserved variables like potential output and output gap besides significant variables like real interest rate, output, and inflation. Moreover, this setting generates time-varying parameters that denote inflation persistence and the contribution of demand- and supply-side factors to inflation. These parameters capture the determinants of aggregate demand and the

⁴⁷For further details on the sensitivity of estimation results to using disaggregated data, see Altissimo, Mojon, and Zaffaroni (2009), Ögünç and Sarıkaya (2011), Özçiçek (2011), Alp, Ögünç, and Sarıkaya (2012), Başer, Kösem, and Ögünç (2012), Erdoğan-Coşar, Kösem, and Sarıkaya (2012), and Tillmann (2012).

policy response to the output gap and the deviation of inflation from the target as well.

In addition, the paper places a special emphasis on the post-crisis period, where the inflation-targeting regime is adjusted to meet the supplementary objective of maintaining financial stability. In doing so, the results highlight the significance of the policy rate, which is closely monitored by market players despite the adoption of complementary monetary policy tools after the crisis. Meanwhile, the paper addresses the zero lower bound issue, which has dominated the advanced economies during this episode. But most importantly, this paper underlines the need to find an accurate measure for representing the stance of the monetary policy to meet the challenges induced by the post-crisis period. In doing so, the paper proposes the natural interest rate, which is sought to be estimated in this context.

Appendix

Non-linear State-Space Models and the EKF

A non-linear state-space model can be represented as

$$x_{k+1} = f_k(x_k) + H_k(x_k)\xi_k \quad (13)$$

$$y_k = g_k(x_k) + \eta_k. \quad (14)$$

The f_k and g_k are vector-valued functions, while ξ_k and η_k represent white-noise processes with the covariance matrices, Q_k and R_k , respectively. The starting values for the EKF algorithm are

$$P_0 = \text{cov}(x_0) \quad (15)$$

$$\hat{x}_0 = E(x_0). \quad (16)$$

As mentioned in Chui and Chen (1991), the updating equations can be written as

$$\begin{aligned} P_{k|k-1} &= \left[\frac{\partial f_{k-1}}{\partial x_{k-1}}(\hat{x}_{k-1}) \right] P_{k-1} \left[\frac{\partial f_{k-1}}{\partial x_{k-1}}(\hat{x}_{k-1}) \right]' \\ &+ H_{k-1}(\hat{x}_{k-1})Q_{k-1}H'_{k-1}(\hat{x}_{k-1}) \end{aligned} \quad (17)$$

$$\hat{x}_{k|k-1} = f_{k-1}(\hat{x}_{k-1}) \quad (18)$$

$$\begin{aligned} K_k &= P_{k|k-1} \left[\frac{\partial g_k}{\partial x_k}(\hat{x}_{k|k-1}) \right] P_{k|k-1} \\ &\times \left[\left[\frac{\partial g_k}{\partial x_k}(\hat{x}_{k|k-1}) \right] P_{k|k-1} \left[\frac{\partial g_k}{\partial x_k}(\hat{x}_{k|k-1}) \right]' + R_k \right]^{-1} \end{aligned} \quad (19)$$

$$P_k = \left[I - K_k \left[\frac{\partial g_k}{\partial x_k}(\hat{x}_{k|k-1}) \right] \right] P_{k|k-1} \quad (20)$$

$$\hat{x}_{k|k} = \hat{x}_{k|k-1} + K_k [y_k - g_k(\hat{x}_{k|k-1})], \quad (21)$$

where equations (17)–(21) denote the optimal Kalman gain, the updated estimate covariance, the updated state estimate, the predicted estimate covariance, and the predicted state, respectively.

In order to apply EKF, the matrices in the state-space representation above should be written in terms of functions, which depend on the unknown parameter vector θ . In other words, let the matrices be represented by $\Phi_k(\theta)$, $G_k(\theta)$, and $H_k(\theta)$. Furthermore, let θ be a random-walk process. In this case, the above equations can be rewritten as

$$x_{k+1} = \Phi_k(\theta_k)x_k + G_k(\theta_k)w_k \quad (22)$$

$$y_k = H_k(\theta_k)x_k + v_k, \quad (23)$$

and the parameter vector is

$$\theta_{k+1} = \theta_k + \zeta_k. \quad (24)$$

The state-space representation using functional form is

$$\begin{bmatrix} x_{k+1} \\ \theta_{k+1} \end{bmatrix} = \begin{bmatrix} \Phi_k(\theta_k)x_k \\ \theta_k \end{bmatrix} + \begin{bmatrix} G_k(\theta_k)w_k \\ \zeta_k \end{bmatrix} \quad (25)$$

$$y_k = [H_k(\theta_k)x_k \quad 0] \begin{bmatrix} x_k \\ \theta_k \end{bmatrix} + v_k, \quad (26)$$

where equations (25) and (26) denote the state-space representation for the state and the observation vector, respectively. The above

model is non-linear, for which EKF can be readily applied. ζ_k shows the white-noise process, for which the covariance matrix is assumed to be $cov(\zeta_k) = S_k = S > 0$. In the particular case where $S = 0$, the parameter vector is assumed to be time invariant, where EKF cannot be operative. If the EKF algorithm is applied to equations (25)–(26), depending on the following starting values,

$$\begin{bmatrix} \hat{x}_0 \\ \hat{\theta}_0 \end{bmatrix} = \begin{bmatrix} E(x_0) \\ E(\theta_0) \end{bmatrix} \quad (27)$$

$$\text{and } P_0 = \begin{bmatrix} cov(x_0) & 0 \\ 0 & S_0 \end{bmatrix}. \quad (28)$$

We obtain

$$\begin{bmatrix} \hat{x}_{k|k-1} \\ \hat{\theta}_{k|k-1} \end{bmatrix} = \begin{bmatrix} \Phi_{k|k-1}(\hat{\theta}_{k-1})\hat{x}_{k-1} \\ \hat{\theta}_{k-1} \end{bmatrix} \quad (29)$$

$$\begin{aligned} P_{k|k-1} &= \begin{bmatrix} \Phi_{k-1}(\theta_{k-1}) & \frac{\partial}{\partial \theta}(\Phi_{k-1}(\theta_{k-1}))\hat{x}_{k-1} \\ 0 & I \end{bmatrix} \\ &\times P_{k-1} \begin{bmatrix} \Phi_{k-1}(\theta_{k-1}) & \frac{\partial}{\partial \theta}(\Phi_{k-1}(\theta_{k-1}))\hat{x}_{k-1} \\ 0 & I \end{bmatrix}' \\ &+ \begin{bmatrix} G_{k-1}(\hat{\theta}_{k-1})\hat{\theta}_{k-1}G'_{k-1}(\hat{\theta}_{k-1}) & 0 \\ 0 & S_{k-1} \end{bmatrix} \end{aligned} \quad (30)$$

$$\begin{aligned} K_k &= P_{k|k-1} \begin{bmatrix} H_k(\hat{\theta}_{k-1}) & 0 \end{bmatrix} P_{k|k-1} \\ &\times \left[\begin{bmatrix} H_k(\hat{\theta}_{k-1}) & 0 \end{bmatrix} P_{k|k-1} \begin{bmatrix} H_k(\hat{\theta}_{k-1}) & 0 \end{bmatrix}' + R_k \right]^{-1} \end{aligned} \quad (31)$$

$$P_k = [I - K_k \begin{bmatrix} H_k(\hat{\theta}_{k-1}) & 0 \end{bmatrix}] P_{k|k-1} \quad (32)$$

$$\begin{bmatrix} \hat{x}_k \\ \hat{\theta}_k \end{bmatrix} = \begin{bmatrix} \hat{x}_{k|k-1} \\ \hat{\theta}_{k|k-1} \end{bmatrix} + K_k \left[y_k - \begin{bmatrix} H_k(\hat{\theta}_{k-1})\hat{x}_{k|k-1} \end{bmatrix} \right]. \quad (33)$$

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Currency Mismatch in the Banking Sector in Latin America and the Caribbean*

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Existing literature uses data based on the residence principle to proxy for currency mismatch. Nonetheless, these data are frequently not disaggregated by currency and cannot identify mismatches in the domestic market. This paper circumvents these issues by constructing a new data set on foreign currency assets and liabilities in the banking sector in Latin America and the Caribbean. The new data reveal a reduction in long foreign currency positions, with several countries taking short positions after 2006. Moreover, employing a methodology that accounts for time-varying unobservable characteristics, this reduction is shown to be partially explained by the implementation of prudential policies.

JEL Codes: G18, G21, F30.

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1. Introduction

The most recent crisis reminded us of the importance of dampening foreign currency risk (see Terrier et al. 2011).¹ Indeed, unexpected movements in the exchange rate may have negative impacts on the balance sheet and, through this channel, amplify risks for financial stability. These risks are particularly relevant in regions with high levels of financial dollarization, such as Latin America and the Caribbean, but despite this fact, insufficient data collection currently exists to properly measure currency mismatches in these economies. As such, the contribution of this paper is twofold. First, it constructs a unique data set to measure currency mismatches in the banking sector in Latin America and the Caribbean by conducting a survey across seventeen central banks from the region. Second, the paper uses this unique data set to evaluate the effects of prudential policies, employing the synthetic control method (Abadie and Gardeazabal 2003 and Abadie, Diamond, and Hainmueller 2010), which, to the best of my knowledge, has never been used to this end.

The contemporary economic history of the Latin American and Caribbean countries has been characterized by periods of high inflation and currency crises. In most countries, these crises reduced confidence in local currencies and, therefore, induced residents to substitute them with U.S. dollars. Indeed, in the majority of Latin American and Caribbean economies, the public began to save, borrow, and lend in U.S. dollars, leading to a process of financial dollarization (see Álvarez-Plata and García-Herrero 2007).²

In turn, financial dollarization is frequently associated with currency mismatches and, therefore, entails significant amounts of financial risk (foreign currency exposure also entails benefits such as international risk sharing; nonetheless, these are beyond the scope of this study).³ In the presence of currency mismatches, unexpected

¹Terrier et al. (2011) highlight the relevance of currency mismatches in Eastern Europe during the crisis.

²The banking sector in Latin America and the Caribbean still is among the most financially dollarized banking sectors in the world (Álvarez-Plata and García-Herrero 2007).

³For instance, Devereux and Sutherland (2009) show in a DSGE model that an emerging economy can achieve international risk sharing by optimally holding foreign currency nominal bonds and issuing claims on capital. In a similar vein, the DSGE model is optimal and achieves risk sharing.

movements in the exchange rate can trigger negative impacts on the balance sheet, and these impacts can propagate throughout the economy, putting financial stability at risk. Furthermore, in the past, this risk has been propagated to a large extent by banking institutions (see, for instance, Corsetti, Pesenti, and Roubini 1999; Krugman 1999; Céspedes, Chang, and Velasco 2000; Aghion, Bacchetta, and Banerjee 2001; and Allen et al. 2002), which emphasizes the need for appropriately measuring currency mismatches in the banking sector, particularly in Latin America and the Caribbean.

This need has been partially addressed by a literature that has constructed different classes of currency mismatch indicators.⁴ The earliest measures in this literature are known as original sin indicators and have been criticized for ignoring the asset side of the balance sheet, i.e., although FX assets can be used to hedge foreign currency risk, they are not considered by the original sin indicators. In response to this flaw, measures that look at both sides of the balance sheet could be used, such as the external vulnerability indicators.

However, these indicators have the problem of using data based on the residence principle, which are frequently not disaggregated by currency of denomination (e.g., balance-of-payment data). Moreover, these data are aggregated at the country level and are, thus, unable to identify mismatches in the domestic market. Hence, the use of country-level data based on the residence principle is even more inappropriate in cases in which residents establish foreign currency relationships on a regular basis (e.g., financially dollarized), such as in Latin America and the Caribbean.

In order to circumvent these issues, this paper collects data on foreign currency assets and liabilities in the private banking sector from financially dollarized economies. The data refer to both sides of the balance sheet, are disaggregated by currency of denomination, and are collected at the sectoral level. Furthermore, because the data collection process has been based on accounting manuals for banking institutions, the information is comparable at the highest possible level across seventeen Latin American and Caribbean countries.

⁴Lane and Shambaugh (2010a, 2010b) should also be considered in this literature. See section 2 for details.

Given these advantages, the paper uses the data to construct two indicators that capture different dimensions of currency mismatch. While the first indicator measures the average level of currency mismatches in a given country and during a given time period, the second indicator informs on whether foreign currency positions have been long or short on average. The behavior of these indicators across countries and over time reveals novel facts.

First, banking sectors with higher levels of currency mismatch were more exposed to foreign currency risk over 2000–12 for two reasons: (i) their currency mismatches were greater on average and (ii) they took more extreme values. Second, there was a reduction in long foreign currency positions in most banking sectors in Latin America and the Caribbean. Third, the trend of the ratio of FX assets to FX liabilities went from increasing to decreasing, and short positions were taken in several banking sectors, mostly after 2006.

The currency mismatch indicators and the synthetic control method are used to investigate the effects of prudential policies (Abadie and Gardeazabal 2003 and Abadie, Diamond, and Hainmueller 2010). The synthetic method controls for unobservable characteristics that vary over time and, therefore, circumvents issues with the standard difference-in-differences techniques (see section 5 for the relevance of unobservable characteristics in evaluating prudential policies). As such, this paper focuses on a policy that is relevant for financially dollarized economies: it investigates the effects of reductions in the limit on long foreign currency positions and of increases in the limit on short positions.

The results suggest that these policies reduced long positions and the average level of currency mismatch in Bolivia, Paraguay, and Peru. On average, over five post-intervention quarters, the policies diminished the ratio of FX assets to FX liabilities by between 1.78 and 2.66 percent, depending on which countries are considered in the construction of the mean.

The study is related to an emerging literature that investigates the effects of FX macroprudential policies on different dimensions of financial risk. For instance, Dell’Ariccia et al. (2012) find that macroprudential tools reduced the probability of credit booms in twenty-two Central and Eastern European countries over 1985–2009. Ostry et al. (2012) show that tighter FX prudential measures are associated

with reductions in domestic foreign currency borrowing. Moreover, Lim et al. (2011) show that limits on foreign lending reduce the procyclicality of leverage, and that limits on net open foreign positions reduce external indebtedness. In contrast with these studies, the present paper constructs measures of currency mismatch by using data disaggregated by currency of denomination on all components of the balance sheet. Furthermore, it uses the synthetic control method and considers as a treatment group the set of countries that have not modified their limits on FX positions.

Finally, some other points are worth mentioning. The currency mismatch indicators that I construct measure the exposure to FX risk that can be inferred from banks' balance sheets. I do not claim in this study that this is all the FX risk that banks face. For instance, the banking sector also faces risk associated with lending to unhedged borrowers (FX credit risk in the terms of Terrier et al. 2011) or with financial instruments that do not appear in the balance sheet (see section 3 for a discussion on the relevance of derivatives). Nevertheless, I believe that both the data set and the indicators that I construct represent a significant improvement over existing literature and contribute to understanding how currency mismatches behave. Furthermore, given that most FX policies in the region apply to the banking sector, the data on banks' balance sheets allow me to perform policy analysis.

The remainder of this paper is structured as follows. Section 2 reviews the literature on currency mismatch indicators. Section 3 explains the main features of the data collection process. Section 4 analyzes the behavior of the constructed indicators across countries and over time, and section 5 performs policy analysis. Finally, section 6 concludes.

2. Currency Mismatch Indicators: Aggregate and Sectoral Levels

The economic crises of the mid and late 1990s involved abandonments of currency pegs and sharp devaluations of local currencies. As such, these crises raised interest among scholars in understanding the nature and implications of foreign currency risk and, therefore, in appropriately measuring currency mismatches. In turn, this interest generated a first generation of indicators that measured

currency mismatches by using data disaggregated at the country level.

The canonical measures in this first generation were the so-called original sin indicators. These measures were based on the idea that currency mismatch was the result of a country's inability to borrow abroad in its own currency (its "original sin"; see Eichengreen and Hausmann 1999; Hausmann, Panizza, and Stein 2002; and Eichengreen, Hausmann, and Panizza 2003).⁵ In this context, the level of currency mismatch in a given economy could be explained by its issuance of foreign currency debt; for instance, some of these indicators argued that original sin and currency mismatch were decreasing in the amount of foreign-currency-denominated securities issued in a country relative to its total debt.

Although the original sin indicators played a pioneering role in literature, their use as proxies for currency mismatch was quickly criticized. The argument was that these indicators considered only the liabilities side of the balance sheet, despite the fact that FX risk could be hedged through purchases and sales of foreign currency assets (Goldstein and Turner 2004). In order to overcome this criticism, one could, in principle, substitute the original sin indicators with measures of external vulnerability. These measures were also constructed at the aggregate level; they considered both sides of the balance sheet and proved powerful for predicting financial crises (Goldstein and Turner 2004).

Nonetheless, the use of external vulnerability indicators as proxies for currency mismatch presents an important flaw. Particularly, these measures employ data based on the residence principle, which are frequently not disaggregated by currency of denomination and are, as a result, inadequate for measuring currency mismatches (Bussière and Mulder 1999 and Goldstein and Turner 2004). In this sense, it may be useful to replace the external vulnerability indicators with the measure developed by Lane and Shambaugh (2010a) to assess the valuation impact of currency movements. This indicator represents an improvement, relative to both the original sin and the external vulnerability indicators, given that it considers the two

⁵In a context in which countries cannot borrow abroad in their own currency, mismatches arise, for instance, because the revenues of most firms are denominated only in this currency.

sides of the international balance sheet and uses data disaggregated by currency of denomination.⁶

However, the problem with this approach is that the measure developed by Lane and Shambaugh (2010a) is based on data aggregated at the country level. Indeed, these data are unable to identify mismatches in the domestic market, given that, in the process of aggregation, long and short foreign currency positions of different residents cancel each other out. Hence, information aggregated at the country level is insufficient for measuring currency mismatches, and this is particularly true for the case of financially dollarized economies, in which residents save, borrow, and lend in foreign currency (Goldstein and Turner 2004 and Rancière, Tornell, and Vamvakidis 2010).

Consistent with this idea, recent literature emphasizes the need to account for currency mismatches in the domestic market by using data disaggregated at the sectoral level. For instance, Allen et al. (2002) emphasize this need by arguing that although foreign currency debt may originate local mismatches, information on this debt is absent in aggregate data. Further, Reinhart, Rogoff, and Savastano (2003) highlight the lack of reliable data to calculate linkages at the sectoral level, thus indicating that data unavailability hinders progress in the literature.

In this context, the present paper constructs currency mismatch indicators that incorporate the improvements in the literature on aggregate measures but, more importantly, use data disaggregated at the sectoral level. That is, these currency mismatch indicators consider both sides of the balance sheet (just as the external vulnerability indicators do); they are based on data disaggregated by currency of denomination (in the manner of Lane and Shambaugh's 2010a indicator) and are constructed at the banking-sector level, thus addressing the concerns raised by recent literature.

In fact, this is not the first attempt to construct currency mismatch indicators for the banking sector; there have been other

⁶The goal of Lane and Shambaugh (2010a) is to quantify the valuation channel. Nonetheless, its characteristics make it suitable for using it as a proxy for currency mismatch. Along the same lines, Lane and Shambaugh (2010b) provide stylized facts on cross-country and time-series variation in aggregate foreign currency exposure.

attempts that do not necessarily incorporate all improvements in the literature on aggregate indicators. For instance, using annual data on foreign currency deposits and loans for thirty-seven countries, Arteta (2005) shows that currency mismatches are greater under exchange rate flexibility. In contrast with the present work, his paper uses data only on specific components of the balance sheet, i.e., credit and loans. Moreover, it employs information up to 2000 and does not investigate the effects of prudential policies. In a different study, Prat (2007) constructs indicators for the banking sector in twenty-five emerging countries, and finds that currency mismatches play a significant role for the determination of emerging sovereign bond spreads. However, her sample does not include most countries with a high degree of financial dollarization considered in the present study (see Goldstein and Turner 2004). Additionally, she uses data up to 2005, does not study the behavior of currency mismatch across countries and over time, and does not evaluate the effects of policy interventions.

Finally, Rancière, Tornell, and Vamvakidis (2010) construct a measure of currency mismatch that controls for bank lending to unhedged borrowers to capture systemic risk. Their measure is constructed for ten European economies and subsequently for another nineteen emerging countries. In this last exercise, they are forced to use data based on the residence principle for most considered Latin American economies. In their own words, the data collection effort in Eastern Europe “seems unparalleled in the rest of the emerging world, despite the role of currency mismatch in the financial crises of the 1990s” (Rancière, Tornell, and Vamvakidis 2010, p. 9). By collecting data on foreign currency assets and liabilities for the banking sector in Latin America and the Caribbean, the present paper fills this gap.

3. Collecting Data and Making It Comparable

3.1 Data Collection Process

The data set presented in this paper was constructed on the basis of a survey that I ran across central banks from Latin American and the Caribbean. The survey had two goals. First, it aimed at generating comparable information that can be easily accessed by the

central banks.⁷ Comparability and accessibility would make the data suitable for performing cross-country comparative studies. Second, it studied financial risks arising from movements in the exchange rate, as well as policies implemented to minimize these risks. Hence, the survey requested information on foreign currency assets and liabilities and on the goals and implementation characteristics of prudential policies and capital flow management measures (see the appendix for a full description of the survey).

This information was collected in two stages. The first stage was launched in November–December 2012, when the project was announced and the survey sent to the chiefs of the research and financial stability departments in each central bank.⁸ Having received the survey, they decided how to distribute the questions among the different departments within their institution, i.e., so that each question would be answered by the best-qualified person. The second stage enabled me to gain a better understanding of the answers, as well as of the economic context in which the policies were implemented, by complementing the information provided in the first delivery of the survey. This second stage comprised a series of contacts made by e-mail or by phone and personal interactions that I maintained with officials from several central banks.

The two stages of the data collection process were designed and implemented to ensure that both goals of the survey were fulfilled. Regarding the first goal, comparability has been guaranteed by the fact that the process was based on the accounting manual for banking institutions from different countries and that officials from all central banks played a proactive role in the construction of the data set (see the next subsection for more details). Moreover, given that researchers from these banks could access the information on foreign currency assets and liabilities, accessibility has also been guaranteed, ensuring that the first goal of the survey was fully achieved. Specifically, the data were uploaded on a website and the security keys for accessing them distributed to the chief economists of the

⁷The Central Bank of Venezuela delivered data on foreign currency assets and liabilities, but at the moment this paper was being written, it had not been analyzed.

⁸The project was announced to the heads of the research departments at the XVII Meeting of the Central Bank Researchers Network of the Americas, held in Montevideo, Uruguay, on November 21–23, 2012.

central banks.⁹ Regarding the second goal, the one referring to risks associated with movements in the exchange rate and policy interventions, the answers to the corresponding questions exceed the scope of this study and have been systematized in related studies (Tobal 2014 and Tobal, forthcoming).

3.2 Making Data Comparable

The two stages of the collection process were designed to ensure the highest possible level of comparability across countries. Particularly, I imposed two conditions that guaranteed cross-country comparability in the data on foreign currency assets and liabilities. I ensured that the information provided by each central bank referred to (i) a similar set of financial agents and (ii) a similar set of foreign currency assets and liabilities.

The heterogeneity across countries allowed defining the set of agents from which the data would be requested by using the two steps of the process. Because the financial systems were heterogeneous, it was a priori difficult to find a single set on which all central banks could provide data and that was, at the same time, sufficiently representative for each country. Given these considerations, I inquired about data on the “banking sector” in the first stage of the process and, then, using this information, redefined the set of agents by discussing the idiosyncratic characteristics of each country with experts from the central banks. Officials from the central banks were better qualified than myself to point out differences and similarities between their financial system and others in the region and, therefore, to judge whether a set of agents was representative for their countries.

As a result, I defined the set of financial agents as “commercial banks,” given that the majority of countries were able to deliver data on these agents and that most central banks agreed that this set was representative enough. The remaining central banks provided information for at least a “similar but slightly more aggregated” set, and were asked which proportion they thought commercial banks

⁹The security keys for accessing the database were distributed at the XVIII Meeting of the Central Bank Researchers Network of the Americas, held in Mexico City, México, on November 11–13, 2013.

Table 1. Commercial Banks in Delivered Set

Country	Proportion of Commercial Banks in Delivered Set
Argentina	99
Aruba	100
Bolivia	100
Brazil	NA
Chile	100
Colombia	100
Costa Rica	100
Dominican Republic Countries	NA
Eastern Caribbean	100
Guatemala	100
Honduras	100
Jamaica	75
Mexico	NA
Nicaragua	100
Paraguay	96
Peru	100
Uruguay	100
Sources: National authorities.	

represented in this set (for those countries that delivered data on a more aggregated set, table 1 lists the proportion that the delivered information represents in “commercial banks”). Indeed, according to their view, commercial banks represent a substantial portion of most financial systems, guaranteeing that the data were also representative in these cases.

The second condition I imposed on the collection process ensured that the data referred to a similar set of assets and liabilities. To fulfill this condition, I guided the central banks in the process of data delivery by explicitly providing them with categories of foreign currency assets and liabilities. Providing officials with specific categories forced them to deliver data on similar concepts and, most importantly, made it harder for them to exclude relevant information.

In creating these categories, I contacted officials from the Banco de la República, Colombia. These officials helped me create five categories of assets and liabilities and linked each foreign currency account from Colombia's accounting manual to one of them. Subsequently, I used this link between accounts and categories as a benchmark for the remaining countries: employing the accounting manual of each country, I linked the accounts of each nation's manual to a Colombian foreign currency account and, therefore, to one of the five categories created by the Banco de la República.¹⁰

The link between foreign currency accounts and categories I created was then sent to the remaining central banks as a guide for data delivery in the second stage of the process. In this stage, central banks were told that they were free to use the link I had created for their country or could create their own by using the link that the Banco de la República, Colombia, had generated.¹¹ The fact that central banks were aware of Colombia's example and had the freedom to use it as a benchmark for creating their own link precluded misinterpretations. Indeed, the fact that officials from the central banks played a proactive role in this step of the process is reassuring, given that they are highly qualified to understand differences and similarities between their financial system and others.

3.3 *Collected Data*

Central banks from seventeen Latin American and Caribbean countries delivered the requested data: Argentina, Aruba, Bolivia, Brazil, Chile, Colombia, Costa Rica, the Dominican Republic, the Eastern Caribbean countries, Guatemala, Honduras, Jamaica, México, Nicaragua, Paraguay, Peru, and Uruguay. The time span of interest was defined as 1992:Q2–2012:Q2, but, knowing that the information would not be available over the entire period for all central banks, I asked them to provide as much information as possible. Furthermore, central banks were told to provide data with a quarterly frequency.

¹⁰For non-Spanish-speaking countries, I employed Monaco's accounting manual as a benchmark, because its structure is similar to that proposed by the Banco de la República, Colombia.

¹¹At this stage, it was emphasized that, even if they created their own allocation, they had to deliver data on all the foreign currency assets and liabilities that appeared in Colombia's example.

Table 2. Data Collected in the Survey

Country	Data Available For:
Argentina	1999:Q4–2012:Q3
Aruba	1999:Q1–2012:Q4
Bolivia	2000:Q1–2012:Q4
Brazil	2001:Q1–2012:Q4
Chile	1992:Q1–2012:Q4
Colombia	2000:Q1–2012:Q3
Costa Rica	1999:Q4–2012:Q3
Dominican Republic Countries	2000:Q4–2012:Q4
Eastern Caribbean	1992:Q1–2012:Q1
Guatemala	2001:Q2–2012:Q2
Honduras	1998:Q1–2012:Q4
Jamaica	2000:Q1–2012:Q4
Mexico	2000:Q4–2012:Q3
Nicaragua	2003:Q1–2012:Q3
Paraguay	1995:Q1–2012:Q3
Peru	2001:Q1–2012:Q4
Uruguay	1999:Q4–2012:Q4
Sources: National authorities.	

In fact, the seventeen countries that delivered information provided quarterly data. The time span for which the information was delivered varied substantially across central banks, along with data availability. For example, while in Chile, Paraguay, and the Eastern Caribbean countries the requested data were available for more than seventy quarters, Nicaragua delivered information on thirty-nine quarters. With the exception of Brazil, Peru, and Nicaragua, whose samples commence in 2001 (Brazil and Peru) and in 2003 (Nicaragua), all countries delivered data starting in the year 2000 or even before that. Table 2 summarizes the time span of the delivered data for each country.

Regarding the set of financial agents upon which the data was delivered, table 1 lists the central banks that delivered information on “commercial banks.” For countries that did not deliver information on this specific set, table 1 also shows the proportion that

“commercial banks” represent in the delivered data (this information is self-reported and, thus, based on the perceptions of central banks’ officials). Particularly, this table shows that only Argentina, Jamaica, and Paraguay provided information on a set of financial agents larger than the requested one. Therefore, in these three countries, the information cannot be separated into data on commercial banks and data on other financial institutions. Nonetheless, according to central bank officials, the set of “commercial banks” represents over 95 percent of the data in Argentina and Paraguay and 75 percent of the data in Jamaica. The information delivered by Jamaica contains data on two types of deposit-taking institutions that are not “commercial banks”: building societies and FIA licensees (institutions with licensees operating under the Financial Institutions Act).

3.4 Flaws in the Data: Financial Derivatives

A drawback of the collected data is that they do not contain all the information required for a full assessment of foreign currency risk. In particular, the data do not contain information on the amount or the nature of financial derivatives. Nonetheless, given that banks may use them to hedge against foreign currency risk, the information is, in principle, relevant to appropriately measure currency mismatches. For example, Goldstein and Turner (2004) note that the lack of information on derivatives is a major flaw of the original sin indicators.

Indeed, the fact that this information is frequently not required to appear in the balance sheet makes it particularly difficult to obtain for most countries. The implication is that Goldstein and Turner’s criticism (2004) applies not only to the original sin indicators but also to most existing indicators on currency mismatch. That is, data unavailability on financial derivatives has hindered the construction of most currency mismatch indicators for most economies.

For the case of Latin America and the Caribbean countries, the fact that the information is generally off balance sheet explains why most central banks were unable to provide data on derivatives when delivering the survey. Furthermore, even in those countries in which the information appears in the balance sheet, accounting manuals

Table 3. Development of Financial Derivatives Market

Country	(Derivatives Assets + Derivatives Liabilities)/(Assets + Liabilities)	Period
Chile	0.0370	2010:M1–2013:M7
Colombia	0.1217	2000:Q1–2012:Q3
Nicaragua	0.0007	2008:M1–2013:M6
Sources: National authorities and author’s calculations.		

tend not to make a relevant distinction between different types of derivatives for the purpose of the present study, i.e., in most Latin American and Caribbean countries, these manuals do not distinguish between derivatives that can, in principle, be used to hedge against foreign currency risk and other types of derivatives.

Furthermore, although using information on financial derivatives is relevant from a conceptual point of view, in practice, not counting with these data may be less critical for the particular case of Latin America and the Caribbean. Precisely, the fact that derivatives markets are relatively less developed in the region makes the lack of information less important. Table 3 supports this point by constructing a proxy for the development of derivatives markets as the ratio of derivatives to the sum of total assets and liabilities in a given country, regardless of currency of denomination.

The proxy is shown for the three economies that delivered information on derivatives. The Central Bank of Chile provided monthly data from January 2010 to July 2013, the information available for Nicaragua is from January 2008 to June 2006, and the Banco de la República, Colombia, delivered quarterly data from 2000 to 2012. Note that the ratio of derivatives to the sum of total assets and liabilities equals 0.0007 and 0.037 for Nicaragua and Chile, respectively, indicating that their derivatives markets are relatively low and moderately developed. The ratio is 0.1217 for Colombia, where the financial derivative market is more developed than in the other two countries. In summary, whereas information on FX derivatives is critical from a conceptual point of view, not having this information is less important for Latin America and the Caribbean in practical terms, because derivatives markets in this region are relatively underdeveloped.

4. Currency Mismatch Indicators

This section presents two indicators that capture different dimensions of currency mismatch in the banking sector. The first indicator is written as follows:

$$CMABS(iT) = \left[\sum_{t=0}^{t=T} |CM(it) - 1| \right] / T,$$

$$CM(it) = FXAssets(it) / FXLiabilities(it), \quad (1)$$

where $FXAssets(it)$ and $FXLiabilities(it)$ are foreign currency assets and liabilities held by the banking sector in country i at quarter t , $CM(it)$ is the ratio between these assets and liabilities, $|\cdot|$ denotes absolute value, the first quarter has been normalized to 0, and $CMABS(iT)$ is the mean of $|CM(it) - 1|$ over time. The consideration of absolute values makes $CMABS(iT)$ silent on whether there is a short or a long foreign currency position. On the other hand, it ensures that these positions do not cancel each other out, and, therefore, that $CMABS(iT)$ reflects the average level of currency mismatch over a period.

Table 4 and figure 1 show the mean and the standard deviation of $|CM(it) - 1|$ over the period 2000–12 for the seventeen countries.¹² The cross-country correlation between the mean and the standard deviation is positive and strong (the correlation coefficient is 0.925 for the seventeen countries). Thus, the countries with higher $CMABS(iT)$ were more exposed to foreign currency risk for two reasons: (i) their currency mismatches were greater on average and (ii) these mismatches were more extreme.¹³

¹²Twelve countries have data available for 2000 and four of the remaining economies have data available starting a year later; therefore, I start the sample with 2000. For the remaining countries, the period considered begins in the first available quarter. For all countries, the period ends in the last available quarter.

¹³Chile, on one hand, is the country with the highest $CMABS(iT)$; the moments of pegged float are associated with an accumulation of long positions in this country (see the appendix for a description of the mismatch trend).

Table 4. Absolute Value Indicator of Currency Mismatch

Country	$CMABS(iT)^*$	Standard Deviation**
Bolivia	0.0415	0.0200
Paraguay	0.0474	0.0385
Uruguay	0.0520	0.0171
Peru	0.0673	0.0479
Dominican Republic	0.0701	0.0671
Honduras	0.0800	0.0224
Costa Rica	0.1077	0.0380
Mexico	0.1107	0.0426
Guatemala	0.1362	0.0598
Brazil	0.1497	0.0857
Argentina	0.2206	0.0842
Colombia	0.2824	0.1698
Aruba	0.2849	0.1052
Jamaica	0.3270	0.2776
Nicaragua	0.3333	0.2306
Eastern Carib. Countries	0.3429	0.2547
Chile	0.3500	0.2862

Sources: National authorities and author’s calculations.

Notes: The sample begins in 2000 or in the first available quarter and ends in the last available quarter; $*CMABS(iT) = \left[\sum_{t=0}^{t=T} |CM(it) - 1| \right] / T$; **standard deviation of $|CM(it) - 1|$.

The second indicator is written as follows for a country i over a period of T quarters:

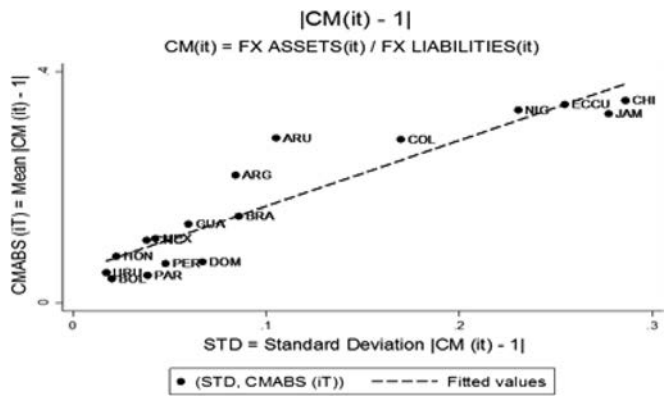
$$CM(iT) = \sum_{t=0}^{t=T} CM(it)/T,$$

(2)

where $CM(iT)$ is the mean of $CM(it)$ over time. This second indicator reflects whether the foreign currency position taken by banks is on average long or short. $CM(iT) > 1$ indicates that the average position is long, and $CM(iT) < 1$ indicates that this position is, on average, short.

Table 5 and figure 2 show rates of change in $CM(iT)$ by country over time. The rate of change is calculated as the

Figure 1. Absolute Value Indicator of Currency Mismatch



Sources: National authorities and author’s calculations.

Notes: The sample begins in 2000 and ends in the last available quarter for each country. For the four countries with no data available for the first the period of 2000, the sample starts with the first available quarter. The countries considered in the figure are ARG (Argentina), ARU (Aruba), BOL (Bolivia), BRA (Brazil), CHI (Chile), COL (Colombia), CRC (Costa Rica), DOM (Dominican Republic), ECCU (Eastern Caribbean Countries), GUA (Guatemala), HON (Honduras), JAM (Jamaica), MEX (Mexico), NIC (Nicaragua), PAR (Paraguay), PER (Peru), and URU (Uruguay).

log-difference between an initial mean (the average of $CM(iT)$ over 2001:Q2–2002:Q1) and a final mean (the average of $CM(iT)$ over 2011:Q3–2012:Q2).¹⁴ For twelve of the sixteen economies considered in table 5, the rate of change is negative, indicating that there was a reduction in long positions in most banking sectors in Latin America and the Caribbean.¹⁵

Furthermore, nine of these banking sectors took short foreign currency positions over 2000–12. For these countries, short and long positions partially cancel each other out and, therefore, $CM(iT) < CMABS(iT) + 1$. Tables 4 and 6 show that this inequality holds

¹⁴The rate of change is calculated between means to avoid a single observation driving the results. The periods 2001:Q2–2002:Q1 and 2011:Q3–2012:Q2 are chosen to calculate the means because all countries, with the single exception of Nicaragua, have data available for these periods.

¹⁵In table 4, the cross-country initial mean is 1.18 and the average of the final mean is 1.03. Figure 3 excludes Chile and Jamaica so as not to distort the scale of the graph.

Table 5. Change in Non-absolute Value Indicator of Currency Mismatch

Country	Initial Mean*	Change in Means**
Brazil	0.730	3.52%
Uruguay	1.046	−0.24%
Bolivia	1.053	−3.14%
Dominican Republic	1.072	−2.83%
Peru	1.094	−3.52%
Honduras	1.100	−0.44%
Paraguay	1.104	−3.37%
Mexico	1.119	−1.79%
Argentina	1.143	0.06%
Guatemala	1.151	−4.49%
Costa Rica	1.164	−3.74%
Eastern Carib. Countries	1.241	−7.74%
Aruba	1.251	4.20%
Colombia	1.347	−8.62%
Chile	1.606	−33.90%
Jamaica	1.680	−19.89%

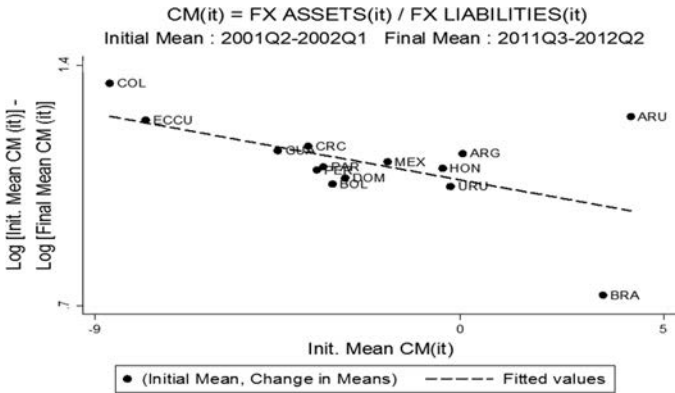
Sources: National authorities and author’s calculations.

Notes: *Initial Mean: Average over 2001:Q2–2002:Q1. **Change in Means: Rate of change between the initial mean and the final mean, which is the average of $CM(it)$ over 2001:Q2–2002:Q1.

for Bolivia, Uruguay, Paraguay, Peru, Brazil, Chile, Colombia, the Dominican Republic, and the Eastern Caribbean countries. The time behavior of $CM(it)$ and its trend are represented in figures 3–11 for these economies (the Hodrick-Prescott filter is used to calculate the trends).¹⁶

¹⁶Note, in these figures, that Brazil is the only country with short positions in almost every quarter. However, pushed by the unification of the FX markets and the modification of reserve requirements on foreign currency positions, its $CM(it)$ increased from 2001 to the late 2000s (I am grateful to officials from the Central Bank of Brazil for pointing this out during the BIS-CEMLA Round Table on FX market interventions). Chile, on the other hand, is the country with the highest $CM(it)$. This can be partially explained by the accumulation of long positions over 1992:Q1–1999:Q3, when the pegged float regime led to several reductions in the price of the Chilean peso. Finally, $CM(it)$ took extreme values in Uruguay and the Dominican Republic in 2003 and 2002, respectively, when these economies faced financial crises.

Figure 2. Non-absolute Value Indicator of Currency Mismatch



Sources: National authorities and author’s calculations.
Notes: The rate of change is calculated between the initial mean (2001:Q2–2002:Q1) and the mean of the period that goes from 2011:Q3 to 2012:Q2. See figure 1 for abbreviations.

Note, in figures 3–11, that most short foreign currency positions were taken over the period that begins in 2007. Furthermore, from 2008 onward, all trends of currency mismatch indicators decreased monotonically (the only exceptions are a few quarters in Chile and Paraguay). In a similar vein, the figures show that there was a break in this trend between 2005 and 2008. Particularly, for most countries, this trend went from increasing to decreasing and reached its minimum over 2002–12, in either 2011 or 2012 for eight of the nine economies (the same pattern is observed in Uruguay if excluding the financial crisis of 2002). As a result, the reduction in long positions and the emergence of short positions are relatively recent phenomena. In other words, short foreign currency positions did not become common in Latin America and the Caribbean until the late 2000s.

Within the set of countries that took short positions, Bolivia, Uruguay, Paraguay, and Peru stand out with similar patterns. First, they are the economies with the four lowest values of $CMABS(iT)$ and four of the five lowest values of $CM(iT)$ (the smallest currency mismatches and the shortest positions, on average). Second, the reduction in their long position was among the greatest over the sample period, even after controlling for initial $CM(iT)$ means

Table 6. Mean in Non-Absolute Value Indicator of Currency Mismatch

Country	$CM(iT)^*$
Brazil	0.8523
Bolivia	1.0337
Uruguay	1.0437
Paraguay	1.0472
Peru	1.0519
Dominican Republic	1.0690
Honduras	1.0800
Chile	1.0934
Costa Rica	1.1077
Mexico	1.1107
Guatemala	1.1362
Argentina	1.2206
Colombia	1.2805
Aruba	1.2849
Eastern Carib. Countries	1.3037
Jamaica	1.3270
Nicaragua	1.3333

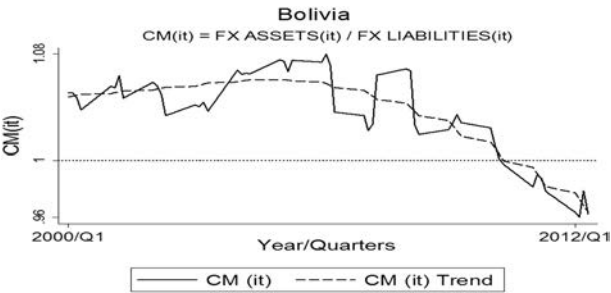
Sources: National authorities and author’s calculations.

Notes: $*CM(iT) = \sum_{t=0}^{t=T} CM(it)/T = \sum_{t=0}^{t=T} (FxAssets(it)/FxLiabilities(it))/T$.

(figure 2 shows that the rate of reduction is increasing in the initial mean, and the four countries appear below the regression line in this figure). Third, given that they have traditionally had a high level of financial dollarization, their central banks and financial supervisors implemented a significant number of policies aimed at reducing it.¹⁷ Hence, it is natural to think that these policies can at least partially explain the joint observation of low $CMABS(iT)$ and $CM(iT)$, and the large reduction in these values. The next section shows that some of the prudential policies taken by Bolivia, Paraguay, and Peru did reduce the values of $CM(iT)$ and $CMABS(iT)$.

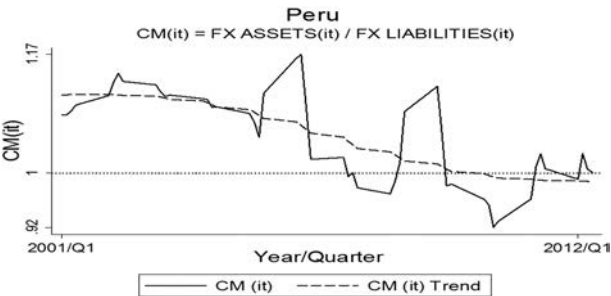
¹⁷See Tobal (2014) for a summary of the amount and types of prudential policies implemented from 1992 to 2012 and also Bailey (2005), Galindo and Leiderman (2005), Cayazzo et al. (2006), Leiderman, Parrado, and Maino (2006), Rennhack and Nozaki (2006), Sánchez (2006), León Rincón and Revéiz Herault (2008), Bacha, Holland, and Gonçalves (2009), and Tapia and Medinacelly (2015).

Figure 3. Time Behavior of $CM(it)$ and Its Trend: Bolivia



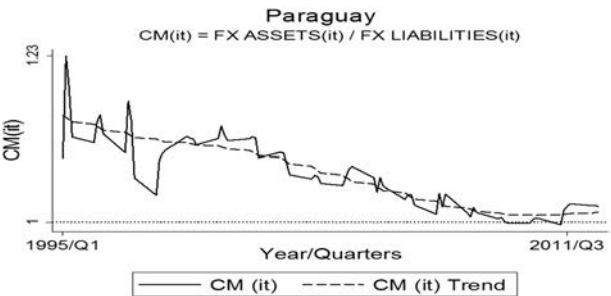
Sources: National authorities and author’s calculations.
Notes: There is a decrease in trend since 2005. The minimum value of the trend is 2012:Q4.

Figure 4. Time Behavior of $CM(it)$ and Its Trend: Peru



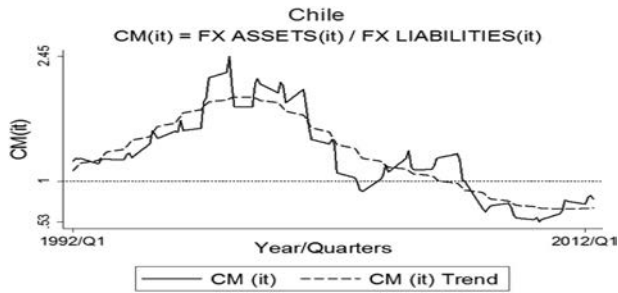
Sources: National authorities and author’s calculations.
Notes: There is a decrease in trend since 2002. The minimum value of the trend is 2012:Q4.

Figure 5. Time Behavior of $CM(it)$ and Its Trend: Paraguay



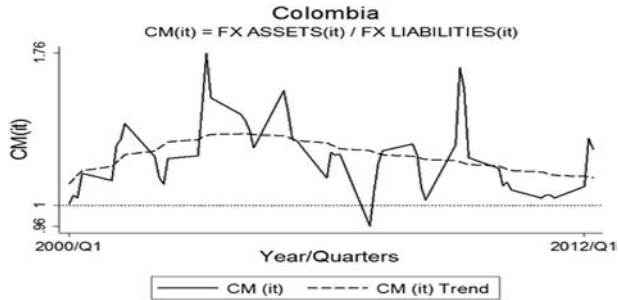
Sources: National authorities and author’s calculations.
Notes: There is a decrease in the trend until 2011:Q3. The minimum value of the trend is 2011:Q3.

Figure 6. Time Behavior of $CM(it)$ and Its Trend: Chile



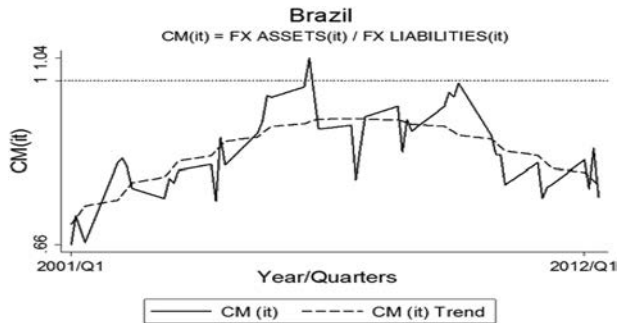
Sources: National authorities and author’s calculations.
Notes: There is a decrease in the trend in 1999:Q1–2011:Q2. The minimum value of the trend is 2011:Q2.

Figure 7. Time Behavior of $CM(it)$ and Its Trend: Colombia



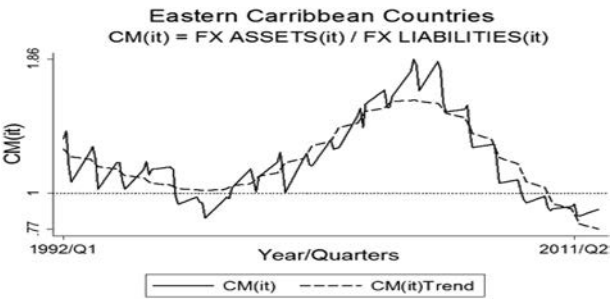
Sources: National authorities and author’s calculations.
Notes: There is decrease in the trend since 2004:Q3. The minimum values of the trend are 2001 and 2012:Q4.

Figure 8. Time Behavior of $CM(it)$ and Its Trend: Brazil



Sources: National authorities and author’s calculations.
Notes: There is a decrease in the trend since 2007:Q3. The minimum values of the trend are 2001–02 and 2011:Q2.

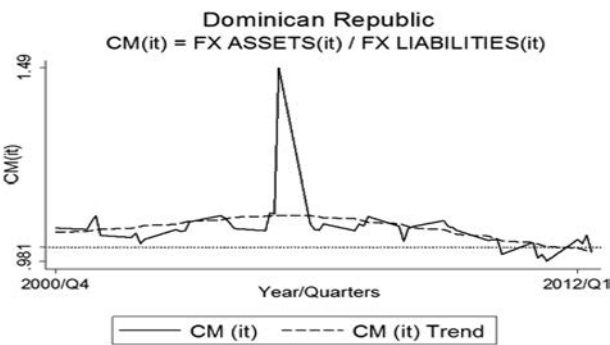
**Figure 9. Time Behavior of $CM(it)$ and Its Trend:
Eastern Caribbean Countries**



Sources: National authorities and author’s calculations.

Notes: There is monotonic decrease in the trend since 2005:Q3. The minimum value of the trend is 2012:Q1.

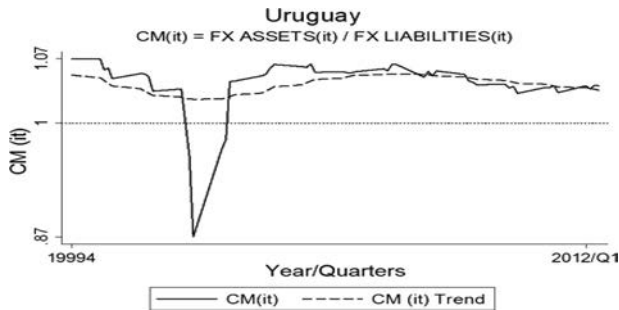
**Figure 10. Time Behavior of $CM(it)$ and Its Trend:
Dominican Republic**



Sources: National authorities and author’s calculations.

Notes: There is a decrease in the trend since 2006:Q1. The minimum value of the trend is 2012:Q4.

Figure 11. Time Behavior of $CM(it)$ and Its Trend: Uruguay



Sources: National authorities and author's calculations.

Notes: There is a decrease in the trend since 2008:Q1. The minimum values of trend are 2001–03 and 2012:Q4.

5. Empirical Analysis

5.1 Analyzed Policies

This section evaluates the impacts of prudential policies on currency mismatches. The analysis focuses on limits on foreign currency positions (limits, hereafter). I concentrate on policies that are relevant for financially dollarized economies and, thus, define the treatment as a reduction in the limit on long positions (e.g., from 70 percent to 50 percent of banks' capital) and/or as an increase in the limit on short positions. I study whether these policies reduced $CM(it)$ (the outcome variable) and infer from the results whether they reduced the mean of $|CM(it) - 1|$.

Bolivia, Peru, and Paraguay are the three economies that implemented these policies over 2000–12 and, therefore, the paper focuses on policies implemented in these countries. This is not surprising, given that these economies have been among the countries with the highest level of financial dollarization and, therefore, among the most proactive ones in changing limits on foreign currency positions (see Tobal 2014 for a reference on this point).

5.2 Methodology

The effect of a policy is the difference between the post-intervention outcome and the counterfactual, i.e., the outcome that would have

been observed in the absence of the intervention. However, when estimating policy effects, comparative case studies replace the counterfactual with the outcome trajectory of a control group. Nonetheless, this trajectory does not replicate the counterfactual properly in the presence of time-varying unobservable characteristics, as in the presence of these characteristics the outcome trajectory of the treated country and that of the control group differ, regardless of the effects of the policy.

This econometric concern is particularly relevant when studying prudential policies, because these measures are intrinsically associated with unobservable characteristics that vary over time. Take the case, for instance, of a country that implements a limit to reduce the growth of currency mismatches in its banking sector (“the treated country”). Notably, the fact that currency mismatches grow relatively fast in this country is likely to be driven by unobservable characteristics. The implication is that, even in the absence of intervention, its outcome trajectory would have been different from the outcome trajectory of other countries in which the policy was not implemented and that belong to the control group.

This fact poses a problem for difference-in-differences techniques, because these methodologies cannot control for time-varying unobservable characteristics and, consequently, yield to biased estimates of policy effects. Along these lines, the use of difference-in-differences techniques has raised important concerns about potential mis-estimates in the recent literature on FX regulation, but also in previous studies investigating the effects of capital account liberalization (see, for instance, Tamirisa 1999; Lim et al. 2011; Bonfiglioli 2005; Dell’Ariccia et al. 2012; and Ostry et al. 2012).

The synthetic control method (Abadie and Gardeazabal 2003 and Abadie, Diamond, and Hainmueller 2010) overcomes the above-mentioned flaw in the difference-in-differences techniques. Particularly, it controls for unobservable characteristics that vary over time by constructing a synthetic unit and using it as counterfactual. The outcome trajectory of the synthetic unit results from assigning a weight, w_j , to the trajectory of each country within the control group. More importantly, the weights are chosen so that the synthetic unit most closely resembles the treated country in the pre-intervention period: the vector of weights W is chosen so as to minimize $(X_1 - X_0W)'V(X_1 - X_0W)$, where X_1 and X_0 and

contain pre-intervention values of outcome variable predictors for the treated and control countries, respectively, and V is a diagonal matrix that reflects their relative importance (see the appendix for a mathematical approach to the synthetic method using the data set in this study). Hence, when constructing the synthetic unit, the synthetic control method accounts for differences in outcome trajectories over the pre-intervention period and, therefore, for unobservable characteristics that vary over time.

5.3 Data Set Application

The analysis is carried out over a period of eleven quarters, centered at the period of the policy intervention, i.e., the limit changes in foreign currency position. This period is normalized at $t = 0$, so that the event window is written as $t \in [-5, 5]$.¹⁸ In the manner of Abadie and Gardeazabal (2003), the outcome variable ($CM(it)$) is included in the matrices X_1 and X_0 . In particular, the predictors' matrices consider three variables: $CM(it)$, the rate of change in the exchange rate, and the exchange rate itself, normalized by its mean value over the event window.¹⁹ Given that the results are similar regardless of whether the latter two predictors are included, this section presents cases in which only $CM(it)$ is considered as a predictor.²⁰ For each policy intervention, the control group is defined as the set of countries that neither reduced the limit on long positions nor increased it on short positions during the event window.²¹

¹⁸Choosing a shorter event window would have left fewer pre-intervention periods to calculate the synthetic weights, while choosing a longer window would have reduced the number of policies available for study.

¹⁹The normalization of the exchange rate ensures that the values are comparable across countries.

²⁰See appendix B in Abadie and Gardeazabal (2003) for a theoretical treatment on the case where the outcome variable is the only predictor. As for the V matrix, it is given by the default option in Stata. This option chooses V using a regression that finds the best-fitting W conditional on this regression.

²¹The synthetic method considers permanent differences in $CM(it)$ originating before the event window, because weights are chosen based on similarities with the treated country. Temporary effects of these policies, however, may alter the time behavior of $CM(it)$ only for a few periods and, thus, contaminate the choice of the synthetic weights. To tackle this issue, I define the control group as those countries that did not implement the policy during the entire event window.

To evaluate a policy, I study the difference between the outcome trajectory of the treated country and that of the synthetic unit after the intervention. However, this difference might be driven by events other than the policy, which occur either at the intervention quarter or during the post-intervention period (the synthetic method accounts for events or policies that occur before the intervention). I follow three strategies to tackle this issue. First, I study differences between average trajectories by taking the mean of $CM(it)$ across (i) treated countries and (ii) their synthetic units. The difference between these average trajectories should be less affected by specific events, because the means are taken over policies implemented by different countries and at different moments in time. Second, I calculate the averages with and without considering Peru; this strategy is relevant because this country experienced several policies of the same type within the same event window. Third, only countries that neither increased the limit on long positions nor reduced the one on short positions during the event window are considered.²²

5.4 Case Studies: Results

This section analyzes policies implemented in the three countries mentioned above: Bolivia, Peru, and Paraguay. Bolivia has now been long considered a financially dollarized economy and has, thus, a long tradition of implementing policies attempting to regulate long foreign currency positions.²³ According to research by officials from the Central Bank of Bolivia, financial dollarization mainly imposes three challenges on their economy (Tapia and Medinacelly 2015): (i) it reduces the power of the central bank to act as a lender of last resort, triggering risks for financial stability; (ii) it clearly diminishes the effectiveness of the monetary policy transmission mechanism by reducing the impacts of changes in domestic money aggregates

²²This requirement only excludes the policies implemented by Honduras.

²³In November 1982, the Bolivian government implemented a series of policy measures to force de-dollarization and then, after a rapid increase in the 1990s, combined changes in reserve requirements, limits on foreign currency positions, and exchange rate regimes to reduce the degree of financial dollarization.

and domestic interest rates on borrowing and lending; and (iii) it is associated with large currency mismatches and, therefore, with significant amounts of foreign currency risk.

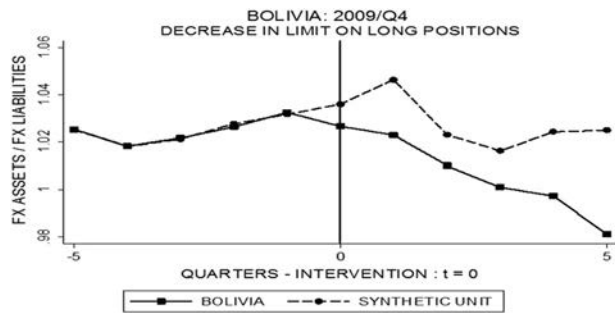
Among the prudential policies taken by Bolivia, this subsection focuses on the measure implemented in 2009, when in December the limit on long foreign currency positions for banks in Bolivia fell from 70 percent of their accounting patrimony to 60 percent of the same base. The policy seems to have sought to further promote the remonetizing process of the Bolivian economy, understood as a process through which households and banking institutions would substitute U.S. dollars with bolivianos in saving, borrowing, and lending (this process is frequently referred to in Bolivia as “Bolivianización”).

Figure 12 shows the behavior of $CM(it)$ during the event window; the solid and the dashed curves depict the trajectories for Bolivia and for the synthetic unit, respectively. The trajectories are close to each other during the pre-intervention period, indicating that the synthetic weights provide a good fit. The reduction of the limit reduced $CM(it)$ by 0.9 percent over the five quarters after the intervention. More importantly, the policy reduced long foreign currency positions: the currency mismatch indicator was lower for Bolivia than it was for the synthetic unit in every quarter of the post-intervention period. Precisely, $CM(it)$ was, on average, 2.45 percent lower for Bolivia. The intervention also reduced the average currency mismatch: whereas the mean of $|CM(it) - 1|$ over the post-intervention period equaled 0.011 for Bolivia, it equaled 0.027 for the synthetic unit.

The possibility that the exchange rate adjusts abruptly has also been a significant source of financial risks in Peru, making this country one of the most proactive Latin American economies in changing its limits on foreign currency positions over the last two decades (Tobal 2014).²⁴ One of the earliest changes undertaken by Peru dates back to 1992, when the financial regulator (“Superintendencia de Banca, Seguros y Administradoras Privadas de Fondos de Pensiones”) established a limit on commercial banks’ short open foreign

²⁴Indeed, the policies implemented in Peru have been significantly spread over time, suggesting that foreign currency risk has been a more frequent source of concern in this country.

Figure 12. Policy in Bolivia

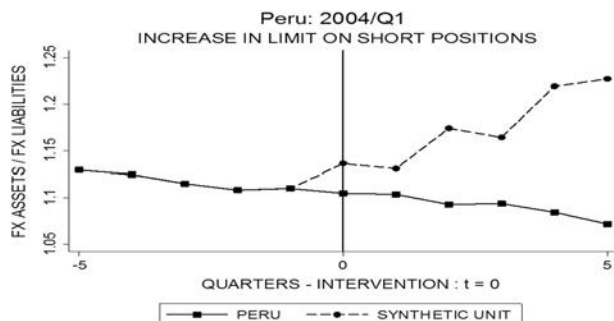


Sources: National authorities and author’s calculations.

exchange position of 2.5 percent of their capital. Research by officials from this institution suggests that the goal of this prudential policy was to avoid the contemporary depreciating trend of the sol damaging banks’ capital (Canta, Collazos, and Shiva 2007).

Nonetheless, by the end of 2003, the trend of the sol reversed. In this context, the emergence of new economic conditions induced the financial regulator to relax the policy undertaken in 1992. In particular, the limit on commercial banks’ short open foreign exchange position increased, going from 2.5 percent of banks’ capital to 5 percent of the same base in 2004. In this framework, it was desirable to reduce exposure to foreign currency risk for banking institutions and to diminish the volatility of the exchange rate.

Figure 13 shows the trajectories of $CM(it)$ associated with the intervention. The trajectories for Peru and for the synthetic unit are similar during the pre-intervention period, signaling a good fit of the synthetic weights. Note in this figure that $CM(it)$ did not decrease by a significant amount after the intervention: the average rate of decrease over the five quarters equaled 0.6 percent. However, the comparison with the counterfactual shows that the policy reduced long positions: the value of $CM(it)$ was lower for Peru in every quarter of the post-intervention period. Specifically, $CM(it)$ was on average 8.2 percent smaller for Peru than for the synthetic unit. Along the same lines, the average of $|CM(it) - 1|$ over the five quarters after the intervention equaled 0.09 for Peru and 0.18 for the synthetic unit.

Figure 13. Policy in Peru

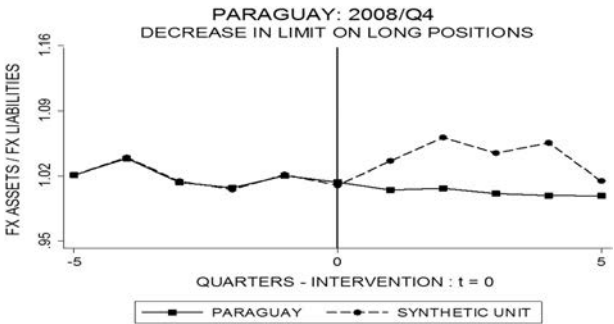
Sources: National authorities and author's calculations.

Paraguay has a long tradition of financial dollarization as well. Just as in Bolivia, the public's willingness to hold U.S. dollars, and thus financial dollarization, deepened in the 1990s as a result of a severe crisis that reduced confidence in the guaraní (García-Escribano and Sosa 2011). Accordingly, this country changed its limits on foreign currency positions multiple times from 1992 to 2012 (Tobal, forthcoming).

One of these policies refers to the change in the limit on long foreign currency positions applied in 2008. In October of that year, the Central Bank of Paraguay reduced this limit, taking it from 50 percent to 30 percent of banks' accounting patrimony. According to officials from this central bank, the implementation of this prudential policy mainly had three goals: (i) diminish volatility in the exchange rate, similar to the changes undertaken from 1992 to 2012; (ii) reduce exposure to foreign currency risk by diminishing currency mismatches; and (iii) reduce potential mismatches of maturity in foreign currency positions.

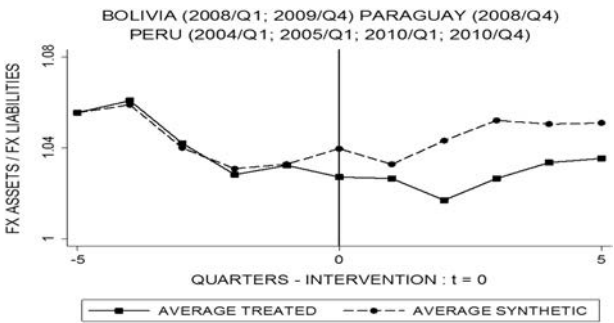
Figure 14 analyzes the intervention and shows that the fit of the synthetic weights is almost perfect during the pre-intervention period. The $CM(it)$ indicator decreased by 0.29 percent on average over the post-intervention period. This indicator was lower for Paraguay in every quarter after the intervention, with an average difference of 3.92 percent with respect to the synthetic unit. Paraguay also performed better than the counterfactual in terms of average mismatches: whereas the mean of $|CM(it) - 1|$ equaled 0.003 for the former, it was equal to 0.042 for the latter.

Figure 14. Policy in Paraguay



Sources: National authorities and author’s calculations.

Figure 15. Averages for Policies in the Treatment

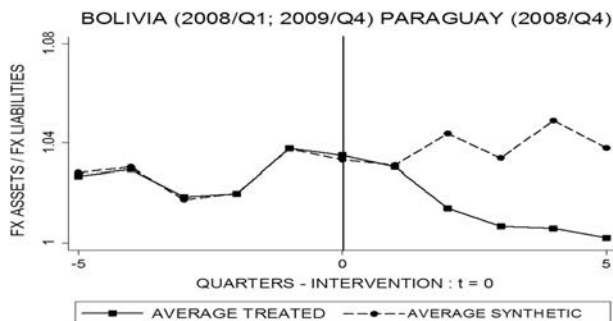


Sources: National authorities and author’s calculations.

5.5 Robustness Checks: Average Trajectories

To check the robustness of the results presented in the previous subsection, I first calculate means across all prudential policies considered in the treatment group. That is, I average the outcome trajectories associated with the policies implemented in Bolivia (first quarter of 2008 and fourth quarter of 2009), Paraguay (October 2008), and Peru (first quarter of 2004, first quarter of 2005, and first and fourth quarters of 2010).

The solid curve in figure 15 shows the average trajectory for the treated countries, and the dashed curve shows the average trajectory for their synthetic units. Note that, on average, the policies

Figure 16. Averages for Policies, Excluding Peru

Sources: National authorities and author's calculations.

considered in the treatment group reduced currency mismatches; the average $CM(it)$ was lower for the treated countries than it was for the synthetic units, with a mean difference of 1.74 percent over the post-intervention period. The policies also reduced the average currency mismatch: the mean of $|CM(it) - 1|$ for the synthetic units was greater than for the treated countries (0.46 for the former and 0.28 for the latter).

A concern about the average trajectories shown in figure 15 is the inclusion of the four policies implemented by Peru. Peru changed the limit on foreign currency positions twice (the intervention under study plus an additional change) within every one of the four event windows. In this context, it may be argued that the difference between the post-intervention trajectories is not driven by the intervention under study (implemented at the intervention quarter). Therefore, to tackle this issue, I recalculate the average outcome trajectories shown in figure 15, excluding the four policies implemented by Peru.

Figure 16 shows the new average trajectories. The policies implemented reduced on average long foreign currency positions: the average of $CM(it)$ was lower for the treated countries than for the synthetic units in every quarter after the intervention; the mean difference between the averages equaled 2.66 percent over the post-intervention period. The mean of $|CM(it) - 1|$ was 0.12 for the treated countries and equaled 0.39 for the synthetic units: the policies also reduced the average level of currency mismatch.

6. Conclusions

In this paper, I have collected data on assets and liabilities in the banking sector of a highly dollarized region, Latin America and the Caribbean. These data have allowed me to construct measures of currency mismatch that circumvent the issues of existing indicators—in particular, the indicators that are based on sectoral-level information and data disaggregated by currency of denomination.

Employing the novel data set, I have shown the existence of new facts. The trend in foreign currency positions broke after 2007 in several banking sectors, which is consistent with a generalized reduction in long foreign currency positions and the emergence of short positions in the second half of the 2000s. I claim that these facts can be partially explained by the de-dollarization policies implemented in the region. Employing a methodology never used to this end, I have evaluated some of these policies in three highly dollarized countries—Bolivia, Paraguay, and Peru—and shown that these policies were successful in reducing long positions and the average level of currency mismatch.

Appendix. Description of the Survey

Section 1 of the survey deals with policies that regulate or give banks incentives to change their foreign currency position, such as reserves and capital requirements associated with these positions. Section 2 covers regulatory policies based on the residence principle, such as taxes, reserve requirements, and limits to external assets and liabilities or capital flows. Section 3 discusses FX interventions. Finally, section 4 studies the same instruments as section 1 but applied to credits and deposits. Each section focuses on three dimensions: they tracked all of the changes in implementing prudential instruments from the beginning to the end of the sample period (June 1992–June 2012), implementation characteristics (e.g., the characteristics of implementation (e.g., “limits established over banks’ capital”), and the goals of the implementation. The survey has been reproduced on the following pages.

Financial Stability and External Imbalances Survey

General Considerations

Section Topics

- Section 1: Instruments that Limit Foreign Currency (FX) Positions or Create Incentives that Deter FX Positions
- Section 2: Instruments that Impact Capital Flows or that Create Incentives for Behavior that Impacts Capital Flows
- Section 3: Interventions in the Foreign Currency Market
- Section 4: Instruments that Limit Foreign Currency (FX) Credit or Create Incentives that Deter FX Credit
- Section 5: Financial Variables

Sample Specifications

Please provide information about the instruments that were being used on June 1, 1992 and about all the policies changes dealing with these instruments within the period specified for each section (see table below).

Note: The period specified for Section 5 begins at the earliest date for which your data is available.

PERIOD OF INTEREST FOR EACH SECTION (DD/MM/YYYY)

Section 1		Section 2	
Period begins: 1-6-1992	Period ends: 1-6-2012	Period begins: 1-6-1992	Period ends: 1-6-2012
Section 4		Section 4	
Period begins: 1-6-1992	Period ends: 1-6-2012	Sample begins: 1-6-1992	Period ends: 1-6-2012
Section 5			
Period begins: earliest date for which data is available	Period ends: 1-6-2012		

Instructions Specific to Sections 1 to 4

Column Labeled “Authorities”

In the tables that appear in Sections 1, 2, and 4 you will find a column labeled “Authorities.” Please indicate which institution(s) was involved in the policy decision and its implementation.

Column Labeled “Level-Feature”

In the tables that appear in sections 1, 2, and 4 you will find a column labeled “Level-Feature.” Please provide information about the level at which the instrument was established and the features of the policy under this column. For instance, in Section 4 for the instrument “limit on FX credit,” you should write: “Established as a percentage over tier 1 capital, applied only to short-term lending” (features of the policy) and “at 15% level” (level at which the instrument was established).

Note: It is important that you provide information about the level and the features of the instruments that were being used on June 1, 1992 and information about all the policies changes dealing with these instruments within the period specified for each section.

Columns Labeled “Goal Weight”

In the tables that appear in Sections 1–4 you will find columns labeled “Goal Weight” that are enumerated. Above each table, you will find a chart with a list of goals that you may have pursued in the appliance of the policies. You should match an enumerated column from the table with a goal from the chart by using the number assigned to it. Determine a weight between 0 and 1 for each goal based on its relevance in the appliance of the policy. Provide also a brief explanation for each goal to which you assign a weight greater than 0 in the same cell where you specify the weight (e.g., *Weight to Goal 1 from Section 1—controlling credit growth—: 0.5; Brief Explanation: the credit growth rate was “higher” than desired*).

The sum of the weights assigned to the goals that appear in every list must be equal to 1. See the following example for Section 4:

LIST OF GOALS FOR SECTION 4
1. Reducing the volatility of the credit cycle 2. Achieving exchange rate stability 3. Reducing loans to borrowers un-hedged from exchange rate variations 4. Correcting current account imbalances 5. Other: please explain briefly

	Commence- End Dates	Level- Feature	Autho- rity	Goal Weight					
				1	2	3	4	5	Total Weight
Instrument	Limit on FX credit								
Initial	01/06/1992– 01/06/1993	Established as a percentage over tier 1 capital, applied only to short-term lending. At 15% level.	Central Bank	0	0.5. Explanation— Residents were borrowing in dollars and selling dollars leading to depreciations of the national currency.	0.5. Explanation— Residents were largely indebted in US dollars and we had no information on how hedged they were from exchange variations.	0	0	1

Instructions Specific to Section 5

In Section 5, provide information about foreign exchange liabilities and foreign exchange assets. The data will be used to construct a comprehensive database that will be available only to the cooperating central banks’ members.

Information Disaggregation

We ask you to please provide information on variables referring to two sectors: the banking sector and the non-banking sector (excluding government). We provide one table listing the variables we think you may have available for the banking sector and another table for the non-banking sector. We will highly appreciate that you provide information of the available variables by quarter frequency (e.g., 2005:Q1, 2005:Q2,...,2012:Q2). However, if the data is not available by quarter, then please provide the highest time-frequency that is available.

Data Availability

Being aware that the information we are requiring is scarce for the 1990s, we have established the beginning of the period of interest as the “earliest date for which your data is available.” We are also aware that you may not have available information for filling all the blanks that appear in the tables for every quarter. We ask you to please fill as many blanks as possible and provide information on as many quarters as you can.

1. Instruments That Limit Foreign Currency (FX) Positions or Create Incentives That Deter Them

Please consider the use of any instruments that limit foreign currency (FX) positions or create incentives for deterring these positions.

Consider the following example regarding the column “Level-Feature:” *“Limit on Bank’s gross positions (liabilities, not assets), spot market, 10% of working capital.”*

Please remember to provide a *brief explanation* for each goal to which you assign a weight greater than 1. Please consider the instruments that were being used on June 1, 1992 (Initial: 01/06/1992) and all the policies changes dealing with these instruments within the period specified (CHANGE 1, and so on).

LIST OF GOALS FOR SECTION 1
1. Controlling credit growth 2. Achieving exchange rate stability 3. Reducing currency mismatches 4. Reducing maturity mismatches of foreign currency positions 5. Correcting current account imbalances 6. Other: please explain briefly

[illegible]

2. Instruments That Impact Capital Flows or Create Incentives for Behavior That Impacts Flows

Please consider the use of any instruments that impact capital flows or that creates incentives for behavior that impacts capital flows.

Consider the example regarding the column “Level-Feature”: reserve required on bank deposits from non-residents, 10% higher than reserves required on bank deposits for residents.

Please remember to give a *brief explanation* for each goal with a weight greater than 1, and to consider both the beginning of the sample period (Initial: 01/06/1992) and subsequent policies with the instrument (CHANGE 1, and so on).

LIST OF GOALS FOR SECTION 2
1. Managing capital flows to control credit growth 2. Achieving exchange rate stability 3. Tilting the composition of inflows towards longer maturity 4. Correcting current account imbalances 5. Other: please explain briefly

[illegible]

3. Interventions in Exchange Rate Market

Please assign weights to the goals, and identify an exchange rate regime and a type of intervention. You will find the list of goals, the exchange rate regimes, and the types of interventions in the following table.

LIST OF GOALS FOR SECTION 3
1. Achieving exchange rate stability to avoid sudden stops. 2. Achieving exchange rate stability for reasons other than 1, 3, or 4 3. Achieving exchange rate stability to reduce the impact of its variations on financial wealth 4. Changing exchange rate to correct current account imbalances 5. Other: please explain briefly

FX REGIMES
1. Fixed exchange rate 2. Float exchange rate 3. Pegged float 4. Target zone exchange rate 5. Dollarization

TYPE OF INTERVENTION
1. Follow a pre-established rule* 2. Discretional interventions *Did the intervention follow a rule for interventions to which the central bank had committed

Date		Number of Operations	Exchange Rate Regime	Type of Intervention	Goal Weight					
					1	2	3	4	5	Total
1992	Q1									0
	Q2									0
	Q3									0
	Q4									0
—	Q1									0
	Q2									0
	Q3									0
	Q4									0
2012	Q1									0
	Q2									0

4. Instruments That Limit Foreign Currency Exchange (FX) Credit or Create Incentives That Deter FX Credit

This section concerns economies that allow financial institutions to extend loans in foreign currency to residents. Please consider the use of any instruments that limit foreign currency credit or aim at deterring this credit. Consider the following example regarding the column “Level-Feature:” limit on FX credit, established as % over tier 1 capital, applied only to short-term lending.

Please remember to provide a brief explanation for each goal with a weight greater than 1, and to consider both the beginning of the sample period (01/06/1992) and subsequent policies dealing with the instrument (CHANGE 1, and so on).

LIST OF GOALS FOR SECTION 4
1. Reducing the volatility of the credit cycle
2. Achieving exchange rate stability
3. Reducing loans to borrowers un-hedged from exchange rate variations
4. Correcting current account imbalances
5. Other: please explain briefly

5. Financial Variables

In this section we ask you to provide information about foreign currency liabilities and foreign currency assets, for the banking sector (excluding government). Our goal is to construct indicators of financial exposure to foreign currency variations. We will highly appreciate that you provide information of the available variables by quarter frequency (e.g., 2005:Q1,...,2012:Q2). We are also aware that you may not have data to fill all the blanks that appear in the tables for every quarter and ask you to please fill as many blanks as you can. Please provide information from the earliest date for which your data is available.

BANKING SECTOR	
Banks' Foreign Currency Assets Position (U.S. Dollars)	Banks' Foreign Currency Liabilities Position (U.S. Dollars)
Foreign Currency Bank Assets Total	Foreign Currency Bank Liabilities Total
Portfolio Investment	Portfolio Liabilities
Equity	Equity
Debt Instruments	Debt Instruments
Short Term	Short Term
Long Term	Long Term
Derivatives	Derivatives
Other Investment	Other Liabilities
Trade Credits	Trade Credits
Loans	Loans
Short-Term Total	Short Term
Short Term to Residents	
Long Term	Long Term
Short Term to Residents	
Money and Deposits	Money and Deposit
Short Term	Short Term
Long Term	Long Term
Other Investment Asset	Other Liabilities

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