

Macroeconomic Effects of Banking-Sector Losses across Structural Models*

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The macroeconomic effects of capital shortfalls in the financial intermediation sector are compared across five dynamic equilibrium models for policy analysis. Although all the models considered share antecedents and a methodological core, each model emphasizes different transmission channels. This approach delivers model-based confidence intervals for the real and financial effects of shocks originating in the financial sector. The width of 90 percent confidence interval for the GDP response to a banking-sector shock produced by a VAR is comparable to the range of outcomes featured in our model-comparison exercise.

JEL Codes: E32, E44, E47.

1. Introduction

The financial crisis has proved a catalyst for academic research to incorporate financial frictions and an explicit role for an intermediation sector in a general equilibrium framework. In addition, the crisis has reignited the interest in the causes and consequences of shocks affecting the balance sheet of banks, as shown for instance by the increased reliance on regulatory stress tests as an instrument of macroprudential policy.

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In this paper, we argue that this research can offer insights into the propagation of capital shortfalls in the intermediation sector to the rest of the economy. Some of this research has been mirrored and expanded at the Federal Reserve Board by different groups of economists. This paper includes models developed by five of these groups. Our original contribution lies in the meta-analysis of results from the different models rather than in the formulation of the models themselves.¹ Although all the models presented share common antecedents and a common methodological core, they have evolved in complementary directions. Accordingly, comparisons of simulation results from these models, with an eye to identifying the structural features chiefly responsible for quantitative differences, can provide a useful assessment of the spillover effects of shortfalls in capital to the rest of the macroeconomy. Moreover, to the extent that quantitative models are needed for policy analysis, and to the extent that different models give starkly different quantitative predictions, it is useful to investigate the origins of these differences.

Each of the models presented emphasizes different aspects of the nexus between a financial sector and the rest of the economy.

- (i) The model by *Iacoviello* allows two financial frictions to coexist in that both bankers and entrepreneurs are constrained in how much they can borrow from patient savers. A key feature of the model is that entrepreneurs own commercial real estate, which enters the production function for final goods and which can be posted as collateral against loans.
- (ii) The model by *Covas and Driscoll* also features credit constraints on bankers and entrepreneurs. In addition, a corporate sector is included so that the banking sector need not fund the entire economy. A key distinction of their approach is that the model is solved with global non-linear methods, rather than by a linear approximation that imposes that all credit constraints are always binding.

¹Each of the five models in this paper is described more fully in related work cited below.

- (iii) The model by *Kiley and Sim* is set up to study the interaction between financial frictions and monetary policy. In all the models covered here, financial intermediaries have access to debt markets and retained earnings. In addition, a key feature of the model developed by Kiley and Sim is that financial intermediaries can access external equity markets to finance their investments, which allows them an explicit treatment of dilution costs related to the expansion of external equity.
- (iv) The interaction between inside and outside equity is also at the center of *Queralto's* model. An agency problem justifies the constraints on borrowing faced by the financial sector in his model. The agency problem is devised in such a way that financial intermediaries face a tradeoff between short-term debt and outside equity. In turn, this endogenous tradeoff is affected differently by different sources of fluctuations.
- (v) Finally, the model developed by *Guerrieri and Jahan-Parvar* is geared to the analysis of monetary policy and takes into account the zero lower bound on nominal interest rates. A salient characteristic of the model is the interaction between two groups of firms. One group of firms can only raise external funds through financial intermediaries, while the other group of firms has direct access to financing from households.

To facilitate comparisons across models, each of the self-contained model sections to follow considers one particular form of capital shortfall, namely a transfer of funds from the banking sector to the household sector. This transfer takes place in a lump-sum fashion and does not distort at the margin the actions of the household sector. Accordingly, it could also be thought of as a shock that simply destroys some assets on the balance sheet of the banking sector. While each model has features that can be used to analyze a plethora of distinct financial shocks, the baseline transfer shock has the virtue of being easily implemented and comparable across all models. In addition, the baseline transfer shock is initially a “pure” financial shock in that it does not imply, per se, the depletion of real resources. In that respect, it is fair to characterize the

macro repercussions as “spillover effects” from the financial sector to the rest of the macroeconomy.

Each model section presents results for the evolution of key macro variables, such as aggregate output, consumption, and investment. It also reports some key financial variables, such as bank capital and spreads between interest rates on deposits and on loans.

Rather than coordinating on the same structural parameters across different models, each model adopts a parameterization best suited to its specific features. Sensitivity analysis with respect to key parameters focuses on plausible changes in calibration that can result in large differences in macro outcomes. From this sensitivity analysis, we learn, for instance, that the choice of labor supply elasticity, while having very little bearing on financial outcomes, can exert an outside influence on the macro spillover effects of financial shocks. More broadly, we highlight that features unrelated to the modeling of financial frictions can be just as important in determining the macroeconomic impact of financial shocks as specific aspects of the financial frictions.

In addition to the effects of the baseline transfer shock, each model section presents the effects of a distinct financial shock that leads to a shortfall in capital for the banking sector, e.g., a housing shock or a change in capital requirements. These additional shocks are calibrated to produce a capital shortfall that is comparable to that of the transfer shock. Because each distinct shock considered has different propagation channels, this exercise provides additional insights on the mechanisms by which financial shocks affect the macroeconomy.

Our model comparisons can deliver “model-based confidence intervals” relative to the effects of financial shocks. The results are informative about the importance of different modeling approaches in influencing the quantitative implications of standardized shocks. Moreover, the sensitivity analysis regarding parameter choices is meant to produce envelope results relative to the possible spillover effects of capital shortfalls. By harmonizing the calibration of the different models, we confirmed that the differences in results highlighted are extant economic differences, rather than differences merely driven by plausible alternative calibrations. Finally, the comparison of shocks other than the baseline transfer shocks across models reinforces the intuition that the underlying causes of a

capital shortfall in the financial sector are important in predicting the subsequent spillover effects to the rest of the economy.²

The rest of the paper proceeds as follows. Section 2 describes the calibration of the baseline transfer shock. Each of the sections from 3 to 7 describes results from individual models. Section 8 provides a horizontal comparison of the effects of the baseline transfer shocks across models. Section 9 concludes. An online appendix, available at <http://www.ijcb.org>, provides additional details on each of the models.

2. Calibration of the Baseline Transfer Shock

In order to provide informative comparisons across the linear and non-linear models considered, the calibration of the size for the baseline transfer shock is chosen to be large but empirically realistic. We consider a transfer shock in line with the results from the stress tests for the U.S. banking sector mandated by the Financial Reform Act. These stress tests, whose main goal is to assess the solvency of the banking system in the face of rapidly deteriorating macroeconomic conditions, provide useful information regarding the magnitude of empirically relevant capital shortfalls. We use the results for the Comprehensive Capital Analysis and Review (CCAR) of 2013. According to these results, under a severely adverse scenario for the U.S. economy, total projected losses of the eighteen bank holding companies included in the stress test amounted to a cumulative total of \$462 billion for the nine quarters from 2012:Q4 through 2014:Q4. For context, these losses are conditional on a scenario designed to be comparable to the Great Recession.³

These losses amount to about 3 percent of 2012 GDP. Only the top eighteen banks by assets were included in the stress-test exercise. To calibrate the baseline transfer shock to capture plausible losses for the entire banking system and not just the largest banks,

²As pointed out in Wieland et al. (2012), model comparison exercises have helped produce influential insights, such as the robustness of the Taylor rule across many models, but are infrequent and costly, because they require the input of many teams of researchers.

³Cumulative losses are disclosed in a press release issued by the Federal Reserve, available at http://www.federalreserve.gov/newsevents/press/bcreg/dfast_2013_results_20130314.pdf.

we scale up the magnitude of the transfer to reflect that the CCAR banks account for about 60 percent of banking assets (the sum of assets of depository institutions and bank holding companies in the flow of funds). Furthermore, a second rescaling is applied to reflect that traditional banks account for about two-thirds of the asset of the banking sector, defined as traditional banking institutions in addition to bank-like institutions.⁴

Accordingly, the *baseline transfer shock* entails a reduction in assets equal to 7.5 percent of GDP ($=3\%/0.6/0.66$) cumulatively over the first nine quarters following the transfer. The shock is phased in using an autoregressive process of order 1 with a persistence equal to 0.9. The desired cumulative transfer over nine quarters is used to pin down the initial innovation to the shock process (roughly 1.2 percent of GDP). Given these choices, after ten years, the total cumulative transfer amounts to about 12 percent of GDP.

3. Matteo Iacoviello: An Estimated Model of Banks with Financing Frictions

3.1 Model Description

The economy in Iacoviello (2015) features four agents: patient households (savers), impatient households (borrowers), bankers, and entrepreneurs. In the following, we present key elements of Iacoviello's model abstracting from a variety of frictions—such as habits, adjustment costs, and variable capital utilization—that bolster the empirical realism of the model. The full model description (including the calibrated parameters for the exercises

⁴The share of assets of traditional banking institutions is derived from the following flow of funds series: $1 - ((\text{FL704090005.Q} + \text{FL734090005.Q}) / ((\text{FL413065005.Q} + \text{FL674090005.Q} + \text{FL614090005.Q} + \text{FL664090005.Q} + \text{FL504090005.Q}) + (\text{FL704090005.Q} + \text{FL734090005.Q})))$, that is: $1 - ((\text{Total Financial Assets of Private Depository Institutions} + \text{Total Financial Assets of Holding companies}) / ((\text{Agency- and GSE-backed mortgage pools; total mortgages; asset} + \text{Issuers of asset-backed securities; total financial assets} + \text{Finance companies; total financial assets} + \text{Security brokers and dealers; total financial assets} + \text{Funding corporations; total financial assets}) + (\text{Total Financial Assets of Private Depository Institutions} + \text{Total Financial Assets of Holding companies})))$.

below) can be found in the online appendix accompanying this paper.

Each agent has a unit mass.⁵ Households work, consume and buy real estate, and make one-period deposits into a bank. The household sector in the aggregate is the net saver. Entrepreneurs accumulate real estate, hire households, and borrow from banks. In between the households and the entrepreneurs, bankers intermediate funds. The nature of the banking activity implies that bankers are borrowers when it comes to their relationship with households, and are lenders when it comes to their relationship with the credit-dependent sector—entrepreneurs—of the economy. Iacoviello designs preferences in a way that two frictions coexist and interact in the model's equilibrium: first, bankers are credit constrained in how much they can borrow from the patient savers; second, entrepreneurs are credit constrained in how much they can borrow from bankers.

Entrepreneurs own housing $H_{E,t}$, priced at q_t , which, combined with household labor, is used by final good firms to produce the final output Y_t . They are subject to a borrowing constraint of the form

$$L_{E,t} \leq m_H E_t \left(\frac{q_{t+1}}{R_{E,t+1}} H_{E,t} \right) - m_N W_{H,t} N_{H,t}. \quad (1)$$

Here, $L_{E,t}$ are loans that banks extend to entrepreneurs (yielding a gross return $R_{E,t}$). The borrowing constraint states that entrepreneurs cannot borrow more than a fraction m_H of the expected value of their housing stock, discounted by the interest rate. The constraint also stipulates that a fraction m_N of the wage bill $W_{H,t} N_{H,t}$ must be paid in advance. Entrepreneurs discount the future more heavily than households and bankers: this assumption guarantees that the borrowing constraint will bind in a neighborhood of the steady state. Denoting with $\lambda_{E,t}$ the Lagrange multiplier on the borrowing constraint, and with $u_{CE,t}$

⁵Except for the introduction of the banking sector, the model structure closely follows a flexible price version of the basic model in Iacoviello (2005), where credit-constrained entrepreneurs borrow from households directly. Here, banks intermediate between households and entrepreneurs.

the entrepreneur's marginal utility of consumption, the first-order condition for loans is

$$(1 - \lambda_{E,t}) u_{CE,t} = \beta_E E_t (R_{E,t+1} u_{CE,t+1}). \quad (2)$$

This first-order condition shows that the credit constraint introduces a wedge in the intertemporal optimization condition of the entrepreneur. Additionally, when this first-order condition is combined with the entrepreneur's factor demands for N_H and H_E , the borrowing constraint acts as a tax not just on the demand for credit but also on the demand for the factors of production.

The other key agents in the model are the bankers, who solve the following problem:

$$\max \sum_{t=0}^{\infty} \beta_B^t \log C_{B,t},$$

where $\beta_B < \beta_H$, and where β_H is the household's discount factor, subject to

$$C_{B,t} + R_{H,t-1} D_{t-1} + L_{E,t} = D_t + R_{E,t} L_{E,t-1} - \varepsilon_t, \quad (3)$$

where D_t denotes household deposits (yielding $R_{H,t}$), $L_{E,t}$ are loans to entrepreneurs, $C_{B,t}$ is bankers' consumption, and ε_t are loan losses suffered by bankers in the conduct of their business. This formulation is analogous to a formulation where bankers maximize a convex function of dividends (discounted at rate β_B), once C_B is reinterpreted as the residual income of the bankers, after depositors have been repaid and loans have been issued. Iacoviello assumes that bankers are constrained in their ability to issue liabilities by the amount of equity capital in their portfolio. This constraint can be motivated by regulatory concerns or by standard moral hazard problems. Letting $K_{B,t} = L_{E,t} - \varepsilon_t - D_t$ denote bank capital at the end of the period (after loan losses caused by transfer shocks have been realized), a capital requirement can be reinterpreted as a standard borrowing constraint, such as

$$D_t \leq \gamma_E (L_{E,t} - \varepsilon_t). \quad (4)$$

Above, the left-hand side denotes banks' liabilities D_t , while the right-hand side denotes which fraction of each of the banks' assets can be used as collateral.

Let $m_{B,t} \equiv \beta_B E_t \left(\frac{C_{B,t}}{C_{B,t+1}} \right)$ denote the bankers' stochastic discount factor, and let $\lambda_{B,t}$ denote the multiplier on the bankers' capital requirement. The optimality conditions for deposits and loans are, respectively,

$$1 - \lambda_{B,t} = E_t (m_{B,t} R_{H,t}), \tag{5}$$

$$1 - \gamma_E \lambda_{B,t} = E_t (m_{B,t} R_{E,t+1}). \tag{6}$$

The interpretation of the two first-order conditions is straightforward. Consider the ways that bankers can increase their consumption by one extra unit today:

- (i) Bankers can borrow from households, increasing deposits D_t by one unit today: in doing so, the banker reduces its equity by one unit, thus tightening the capital requirement one-for-one and reducing the utility value of an extra deposit by $\lambda_{B,t}$. Overall, today's payoff from the deposit is $1 - \lambda_{B,t}$. The next-period cost is given by the stochastic discount factor times the interest rate R_H .
- (ii) Bankers can consume more today by reducing loans by one unit. When lending less, bankers face a tighter capital requirement, since the reduction in loans mechanically translates into a reduction in equity. The utility cost of tightening the borrowing constraint through lower loans is equal to $\gamma_E \lambda_{B,t}$. Intuitively, the higher the value of loans as collateral for the bank activity (the higher γ_E is), the larger is the utility cost of not making loans. Overall, today's cost of making a loan is $1 - \gamma_E \lambda_{B,t}$. The next-period benefit is given by the stochastic discount factor times the interest rate R_E .

For bankers to be indifferent between collecting deposits (borrowing) and making loans (saving), the returns across assets must be equalized. Given that R_H is determined from the household problem, bankers will be borrowing constrained, and λ_B will be positive, so long as $m_{B,t}$ is sufficiently lower than the inverse of R_H . In turn,

if λ_B is positive, the required return on loans R_E will be higher, the lower γ_E is. Intuitively, the lower γ_E is, the lower is the liquidity value of loans in relaxing the bankers' borrowing constraint, and the higher is the compensation required by bankers to be indifferent between lending and borrowing. Moreover, loans will pay a return that is (near the steady state) higher than the cost of deposits, since, so long as γ_E is lower than one, loans are less liquid than the deposits.

The bankers' capital requirement on the one hand, and the entrepreneurs' credit constraint on the other, create a wedge between steady-state output in absence of financial frictions and output when financial frictions are present. The capital requirement on banks limits the amount of savings that banks can transform into loans. Likewise, the credit constraint on entrepreneurs limits the amount of loans that can be invested for production. Both forces lower steady-state output.

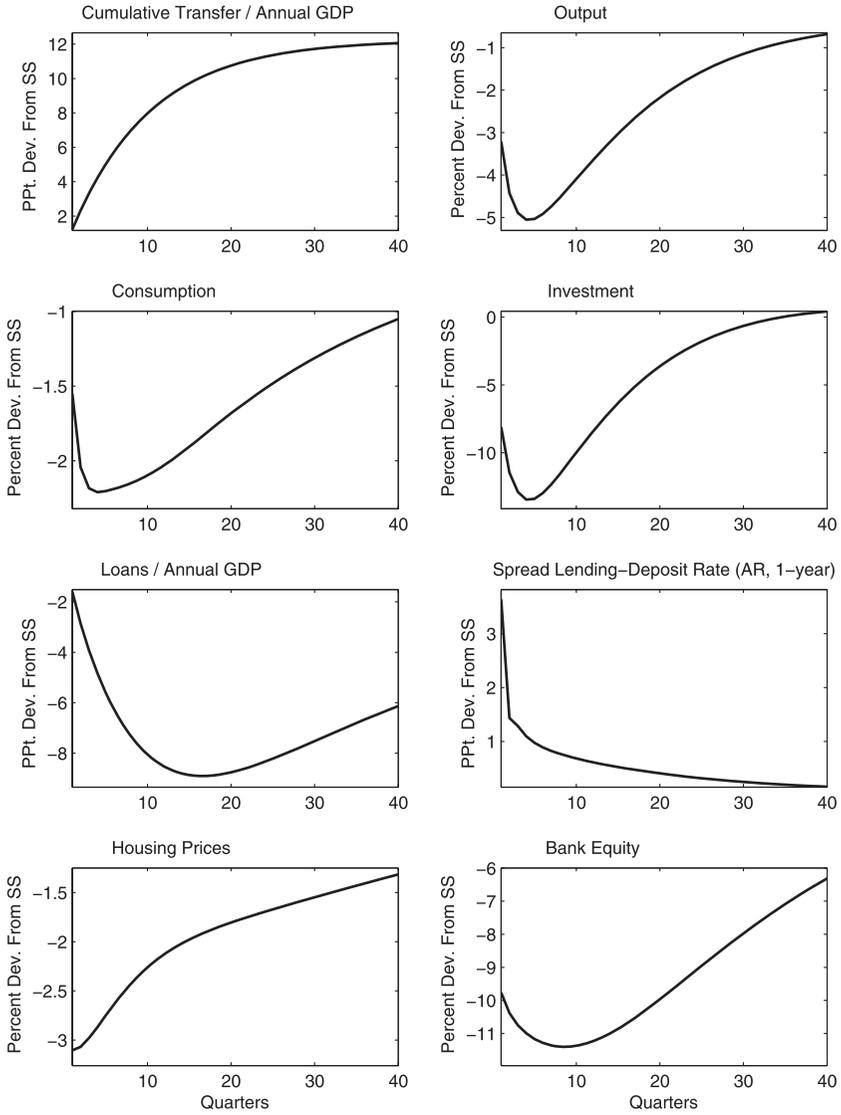
3.2 *Transfer Shock*

Analogous forces are also at work for shocks that move the economy away from the steady state, to the extent that these shocks tighten or loosen the severity of the borrowing constraints. To illustrate their importance, consider the dynamic effects of a transfer shock ε_t . An interpretation of this shock is that it captures losses for the banking system caused by a wave of defaults. Figure 1 plots a dynamic simulation for the model economy. The stochastic process for ε_t follows:

$$\varepsilon_t = 0.9\varepsilon_{t-1} + \iota_t. \quad (7)$$

The transfer shock is calibrated as already discussed in section 2. The shock impairs the bankers' balance sheet, by reducing the value of bank assets (total loans minus loan losses) relative to the liabilities (household deposits): at that point, in absence of any further adjustment to either loans or deposits, bankers would have a capital asset ratio that is below target. Bankers could restore their capital-to-asset ratio either deleveraging (reducing deposits from households) or reducing consumption in order to restore the equity cushion. If reducing consumption is costly, bankers reduce loans and give rise to a vicious, dynamic cycle of reductions in

Figure 1. Transfer Shock in Iacoviello's Model



both loans and deposits, which propagates the credit crunch. In particular, the decline in loans to the credit-dependent sector of the economy (entrepreneurs) acts as a drag on consumption and productive investment. It drags investment down because credit-constrained entrepreneurs reduce their real estate holdings and labor demand as credit supply is reduced. And it drags consumption down because the decline in labor demand and the reduction in entrepreneurial investment induce a decline in total output. All told, GDP declines almost 5 percent after about one year.⁶

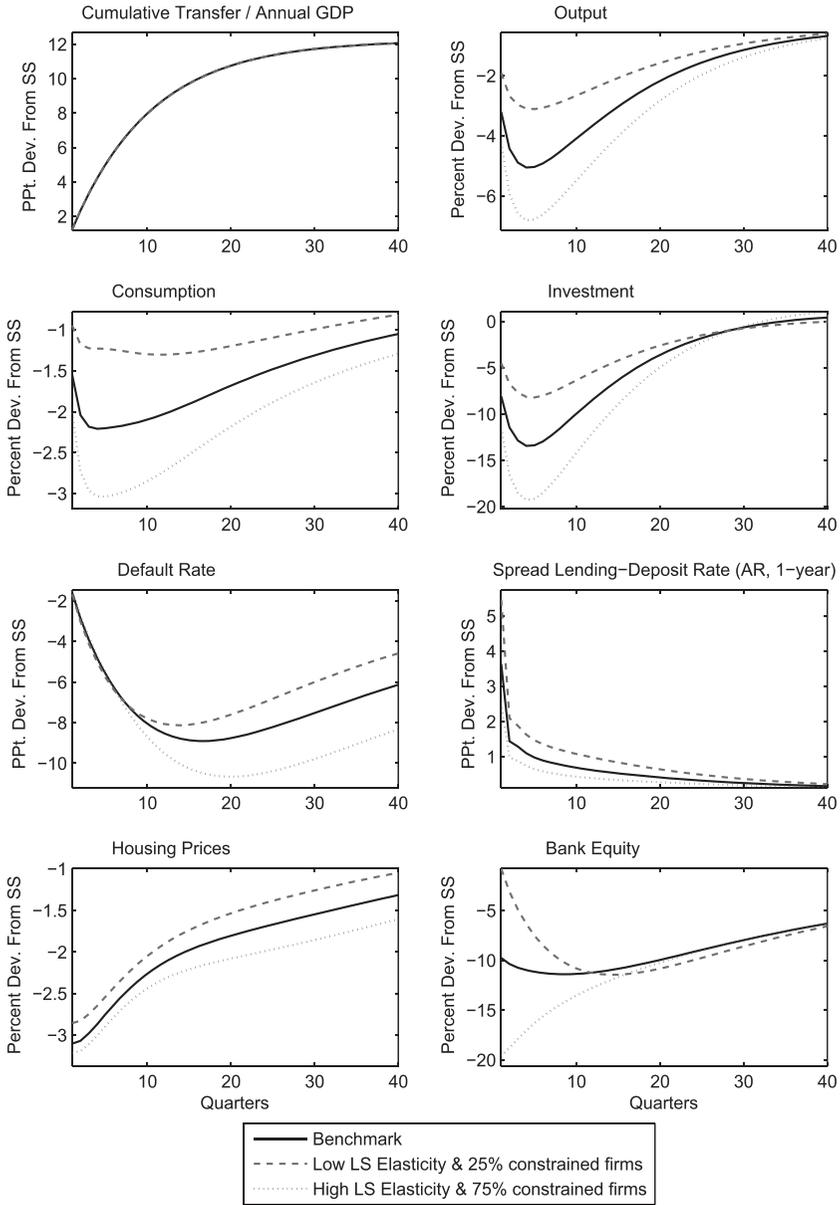
3.3 Robustness Analysis

Figure 2 presents robustness analysis around the baseline parameterization. In the benchmark case, labor supply elasticity is 2, and the capital share of credit-constrained entrepreneurs is about one-half. A higher labor supply elasticity and capital share of constrained entrepreneurs both work to reinforce, as one would expect, the effects of a shock to bank capital. A lower labor supply elasticity (slightly less than 1) and a 25 percent share of credit-constrained entrepreneurs both work to reduce the magnitude of the decline in output from 5 to 3 percent. Conversely, a higher labor supply elasticity (around 5) and a 75 percent share of credit-constrained entrepreneurs concomitantly boost the decline in economic activity from 5 to 7 percent.

Figure 3 considers the effects of another shock that endogenously leads to a reduction in bank capital, namely a decline in housing prices. Through a decline in lending activity, consumption, and investment, the shock to housing prices leads to a reduction in bank capital, even in the absence of direct shocks to bank capital (such as those taking place with the transfer shock). When the housing price shock is sized to reduce bank equity by 10 percent (namely, the same percent decline in bank equity following the transfer shock), aggregate output falls by approximately 4 percent, slightly less than in the case of the transfer shock.

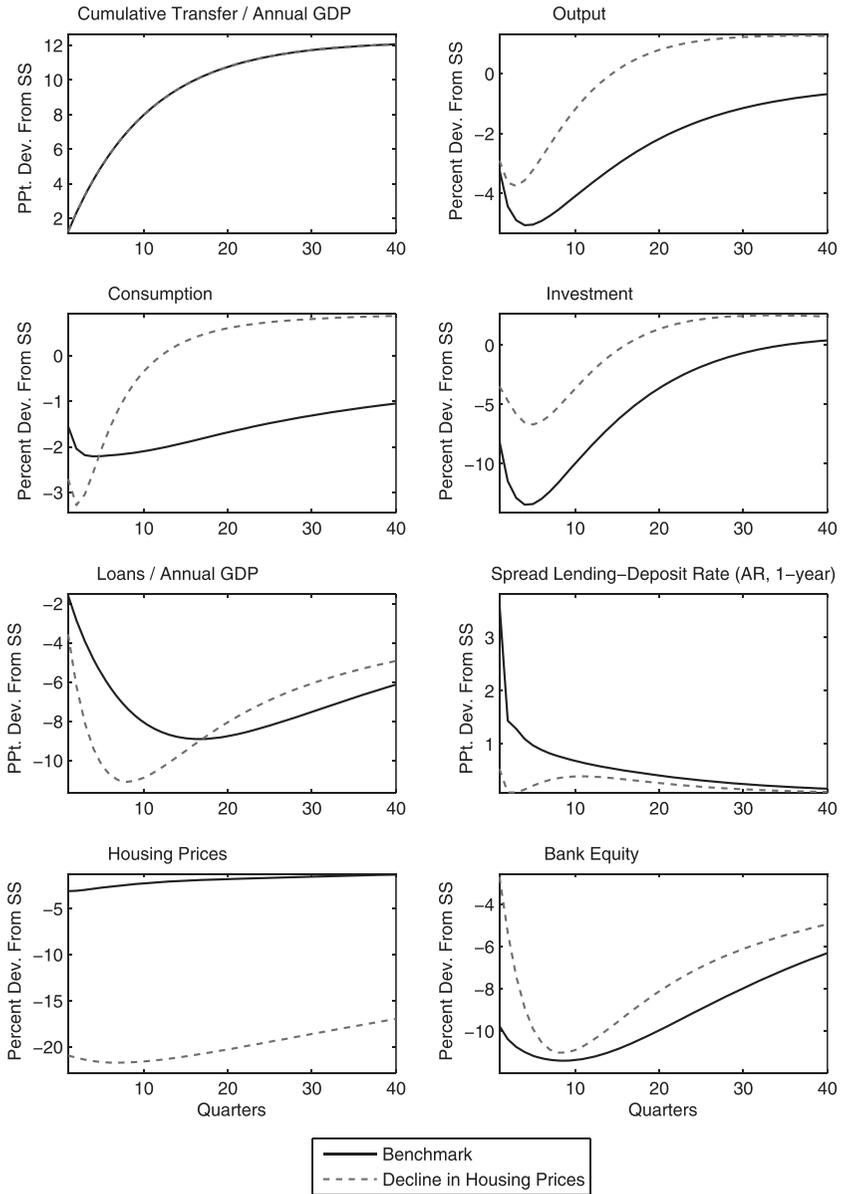
⁶An additional force that reduces output in the wake of a transfer shock is a negative wealth effect on labor supply for the households who receive funds from the bank. This effect contributes to less than one-quarter of the decline in output.

**Figure 2. Transfer Shock in Iacoviello’s Model:
Robustness Analysis**



Notes: In the benchmark case, the labor supply elasticity is around 2, and the capital share of credit-constrained entrepreneurs is about one-half. A higher labor supply elasticity and a higher capital share of constrained entrepreneurs both work to reinforce the effects of a shock to bank capital. The lower labor supply elasticity considered is slightly less than unity. The higher labor supply elasticity considered is nearly 5.

Figure 3. Transfer Shock vis-à-vis a Housing Price Shock in Iacoviello's Model



Notes: The figure considers the effects of a shock to housing prices that leads to a decline in bank equity comparable to the decline induced by the transfer shock.

4. **Francisco Covas and John Driscoll: A Non-linear Model of Borrowing Constraints**

4.1 Model Description

The model of this section is also described in Covas and Driscoll (2013). That paper evaluates the aggregate effects of imposing a liquidity coverage ratio requirement in addition to a risk-based capital requirement on the banking sector. Covas and Driscoll sketch key features of their model below.⁷ The model is based on that of Aiyagari (1994), in which a continuum of heterogeneous workers are subject to idiosyncratic labor income risk under the presence of a borrowing constraint. In addition, the model adds heterogeneous entrepreneurs who face investment risk under the presence of a borrowing constraint and heterogeneous bankers which are subject to profitability risk and a capital requirement.⁸ The model with workers and entrepreneurs is very similar to the model specifications used by Angeletos (2007) and Covas (2006). The banker's problem is similar to the partial equilibrium setup analyzed by De Nicolò, Gamba, and Lucchetta (2013). The key frictions in the banking sector are the capital requirement and the inability of bankers to issue outside equity, that is, all the increase in equity occurs via retained earnings. The combination of these two frictions and the fact that entrepreneurs are assumed to be bank dependent creates a setting in which the Modigliani-Miller theorem does not apply.⁹ As a result, an exogenous shock to bankers' equity leads to adjustments in the supply of credit by banks and loan spreads, with corresponding real effects.

⁷The full model description (including the calibrated parameters for the exercises below) can be found in the online appendix accompanying this paper.

⁸To better preserve comparability with the other models, for the simulations below the liquidity requirement is not included.

⁹The assumption of bank dependence for the entrepreneurial sector is in accordance with the literature on the credit channel of monetary policy, which also assumes that some firms, particularly smaller ones, do not have the same amount of access to other forms of finance.

Workers supply one exogenous unit of labor to the entrepreneurs and a corporate sector. They are subject to labor productivity shocks that affect their earnings. They choose consumption, deposits, and asset holdings to maximize utility subject to a borrowing constraint. Entrepreneurs can invest in an individual-specific risky technology and in riskless securities. They supply one exogenous unit of labor to their entrepreneurial businesses and also to the corporate sector. Entrepreneurs choose consumption, investment, and loans (from the banking sector) to maximize lifetime utility subject to a borrowing constraint. The reliance on bank loans as a form of finance and the presence of a borrowing constraint violate the Modigliani-Miller theorem for the entrepreneurial sector, in which changes in the quantity and price of bank loans force entrepreneurs to chance the consumption and investment choices.

Bankers hold loans and riskless securities; the latter, which are assumed to be in positive net supply, may also be used to fund loans, and therefore net securities holdings may be negative. Loans mature at a constant rate and have a constant servicing cost; to capture the illiquidity of loans relative to securities, banks pay (asymmetric) adjustment costs to changing the quantity of loans outstanding. In addition, loans and other banking activities generate non-interest income which is a concave function of the size of the loan portfolio and is subject to idiosyncratic profitability shocks. Loans are funded through deposits and equity. Banks face a risk-based capital constraint, in which the amount of equity must be at least equal to a risk-weighted sum of loans and securities (the latter of which has a zero risk weight). Bankers maximize utility subject to the above constraints. In equilibrium, banks will choose to hold a (precautionary) buffer of equity capital above the requirement; however, the capital constraint may still bind for some banks. As mentioned earlier, bankers are not allowed to issue outside equity, and the increase in capital has to be done via retained earnings.

The model is completed by a corporate sector, which produces output with capital supplied by workers and labor supplied by both workers and entrepreneurs. This sector is included so that the banking sector need not fund the entire economy.

Table 1. Selected Moments of Covas and Driscoll’s Model

Moments	Data	Model
Tier 1 Capital Ratio	10.0	9.7
Share of Constrained Banks	0.1	0.3
Leverage Ratio	7.0	6.3
Adjusted Return on Assets, % (AR)	2.9	3.4
Cross-Sectional Volatility of Adjusted Return on Assets	1.3	1.4
Safe Assets Held by Banks, %	33.1	34.4
Ratio of Interest Income to Non-interest Income	1.3	0.3
Share of Non-interest Expenses	3.0	8.5
Return on Securities, % (AR)	0.5	0.5
Loan Rate, % (AR)	4.0	4.1
Consumption to Output	0.7	0.7
Banking Assets to Output	0.9	1.2
Safe-to-Total Assets	0.3	0.3
Memo: Deposit Rate, % (AR)	0.1	0.1

Notes: Moments are based on sample averages using quarterly observations between 1997:Q1 and 2012:Q3, with the exception of the percentage of safe assets held by banks, which is only available starting in 2001:Q1, and averages for the ratio of interest income to non-interest income and banking assets to output are calculated only for the period after the fourth quarter of 2008 when investment banks became bank holding companies. The adjusted return on assets is defined as net income excluding income taxes and salaries and employee benefits. The percentage of safe assets held by banks includes all assets with a zero risk weight plus assets with a 20 percent risk weight. The sample includes all bank holding companies and commercial banks that are not part of a BHC, or that are part of a BHC which does not file the Y-9C report. The share of constrained banks is estimated using banks’ responses in the Senior Loan Officer Opinion Survey and reported by Bassett and Covas (2013). The safe-asset share is obtained from Gorton, Lewellen, and Metrick (2012). All interest rates reported are annual.

In steady-state equilibrium, the loan, security, and deposit markets clear, factor prices equal marginal products, and distributions of agents’ characteristics are invariant. The model is calibrated so that parameters from the bankers’ problem match certain moments from bank holding company Call Report data as summarized in table 1. A summary of the calibration of the model is provided in the online appendix. The model is solved numerically by iterating the policy function over time, as in Coleman (1990).

Table 2. Details of the Transfer Shock in Covas and Driscoll's Model

Sector	Year 1	Year 2
Workers	0.9	0.6
Entrepreneurs	0.2	0.2
Bankers	-37.3	-24.5

Note: Entries in the table denote the size of transfer in each year as a percent of the steady-state level of wealth of each sector.

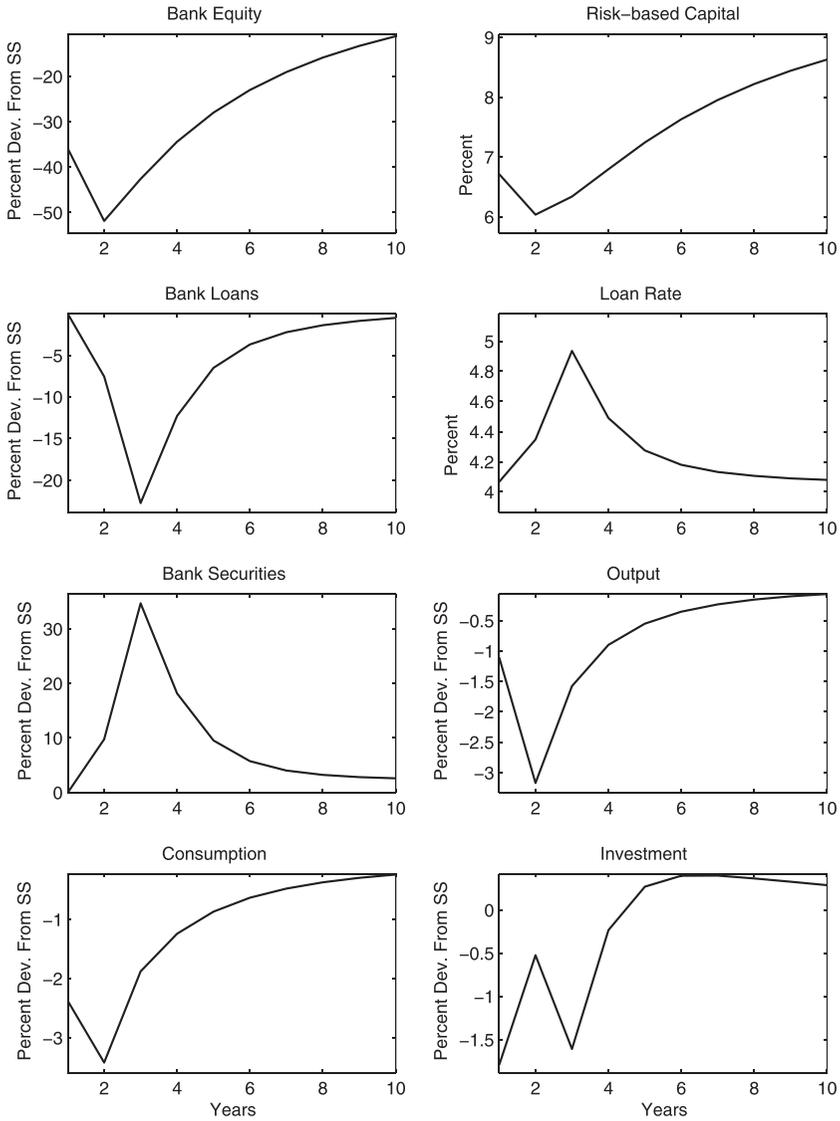
The steady-state solution also solves for the loan rate, the return on securities, and the capital-labor ratio of the corporate sector using a quasi-Newton method. Finally, the simulation results presented below are based on transition dynamics which simulate the evolution of the density function for each sector using the optimal policy functions and the time path for the loan rate, the return on securities, and the capital-labor ratio of the corporate sector.

4.2 *Transfer Shock*

The baseline simulation reports the effects of a transfer of wealth from bankers to entrepreneurs and workers equivalent to 7.5 percent of steady-state output, in line with the calibration of the shock discussed in section 2. Furthermore, we assume that 60 percent of the transfer occurs in the first year, and 40 percent in the second year (hewing closely to the quarterly autoregressive progress with a coefficient of 0.9 as for the other models in this paper). The transfer of wealth between the three sectors is assumed to be unexpected in both years. Table 2 gives the size of the transfer in each year relative to the level of steady-state wealth of each sector.

The large reduction in bankers' wealth drives down bank equity by about 35 percent in the first year and 50 percent in the second year, as seen in figure 4. This generates a reduction in the average tier 1 ratio of 300 basis points in the first year and 70 basis

Figure 4. Transfer Shock in the Covas/Driscoll Model



points in the second year. Despite the larger decrease in wealth in the second year, the decrease in the tier 1 ratio is lower in the second year because the large majority of banks have a binding tier 1 capital ratio which cannot go below 6 percent. In order to meet the capital requirement, banks slash consumption (i.e., dividends) by 40 percent in the first year and 60 percent in the second year, reduce loan outstandings by about 8 percent in the first year and 23 percent in the second year, and increase holdings of securities by 10 and 35 percent in years 1 and 2, respectively.¹⁰ The abrupt reduction in loans hinges partially on the assumption that bankers do not have access to outside equity and in our model all equity capital accumulation is done via retained earnings. The magnitude of the transfer shock would likely be dampened if banks had access to outside equity or started the exercise with a larger capital buffer. The reduction in the supply of loans by banks causes the loan rate to increase by about 30 basis points in the first year and 65 basis points in the second year, and, similarly, the rate on securities to fall by 40 and 110 basis points, respectively. The change in these two interest rates combined implies that the loan spread would increase by 70 basis points in the first year and 170 basis points in the second year.

The transfer shock initially benefits the entrepreneurs, with both wealth and consumption increasing by small amounts for the first two years. However, the increase in the loan rate reduces investment by entrepreneurs and causes their wealth and consumption to fall in subsequent years. As a result, entrepreneurs' capital and holdings of securities fall, as do their labor demand and output. Investment is initially negative, before rising as the economy returns to its steady state.

Throughout the transition period, workers are better off, as they receive the benefit of increased wealth without incurring the direct cost of higher loan rates since they do not borrow from banks. In response to an increase in wealth, workers increase consumption and savings. Some of the increase in savings is done through the accumulation of capital that is rented to the corporate sector, whose output rises as a result.

¹⁰Based on Call Report data, total loans at commercial banks declined by 10 and 6 percent in 2009 and 2010, respectively.

In the aggregate, consumption and output both fall by about 3 percent in the second year of the transfer shock, and investment declines by about 1 percent. The decline in investment is less pronounced relative to the decline in output because of the large boom in investment in the corporate sector.¹¹

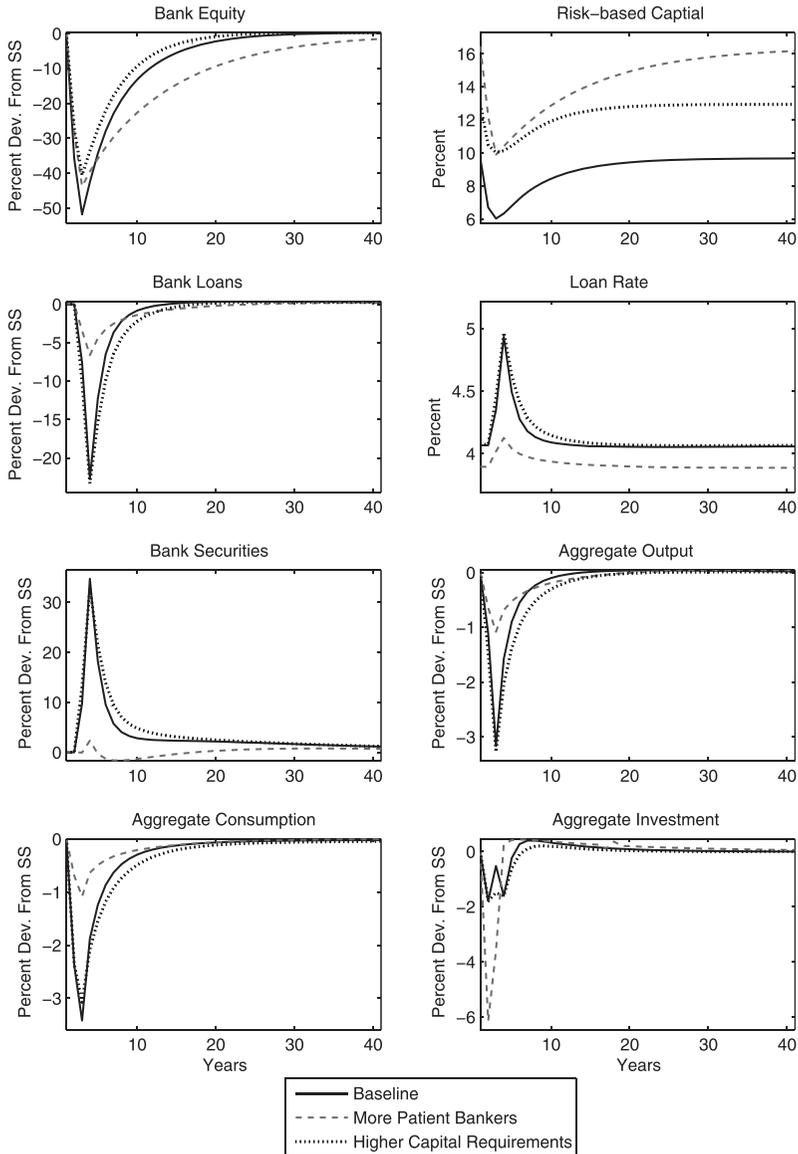
4.3 *Sensitivity Analysis*

A key feature of the model is the capital requirement for bankers. As shown in table 1, the capital requirement constraint binds for about one-third of banks in the steady state. The capital constraint is the key friction in the banking sector, and for that reason we conduct two types of sensitivity analysis. In the first exercise, we reduce the fraction of capital-constrained bankers to about half of the steady-state share. We do so by increasing the discount factor of bankers, which increases the size of the capital buffer above the minimum capital requirement. In the second exercise, we also increase the amount of equity held by bankers. However, we do so by raising the capital requirement, and so the capital buffer above the minimum remains relatively unchanged. We show in figure 5 that these two experiments generate different sets of aggregate responses, and we conclude that the key driver of bankers' responses following the transfer shock is the share of capital-constrained banks.

Reducing the share of capital-constrained banks reduces the effects of the transfer shock—output and consumption now both decline by about 0.6 percent in the first year and 1 percent in the second year. Since bankers have larger capital buffers when the transfer shock occurs, the responses of bank loans and the corresponding interest rate are considerably less pronounced in this case. In particular, the transfer shock now increases the loan rate only by 20 basis points, and the return on securities declines by 10 basis

¹¹This result is a bit counterintuitive. The reason is that the transfer shock is very large and bankers cannot absorb more deposits because the capital constraint binds for almost all banks. In equilibrium, workers invest even more in the corporate sector. In the next section, we reduce the share of constrained banks and get the standard result that the response of investment is larger (more negative) than the response of output.

Figure 5. Transfer Shock in the Covas/Driscoll Model: Robustness Analysis



Notes: Under the baseline calibration the fraction of capital-constrained bankers is 0.3 in the steady state. Under “More Patient Bankers,” an increase in the discount factor of bankers reduces the fraction of capital-constrained bankers to 0.15 by increasing the capital buffer above the statutory minimum. Under “Higher Capital Requirements,” the increase in the discount factor is accompanied by an increase in the capital requirement, sized so that the buffer over the statutory minimum is unchanged relative to the baseline calibration.

points. As a result, the spillover effects of the shock in the banking sector to the entrepreneurial and worker sectors are considerably smaller.

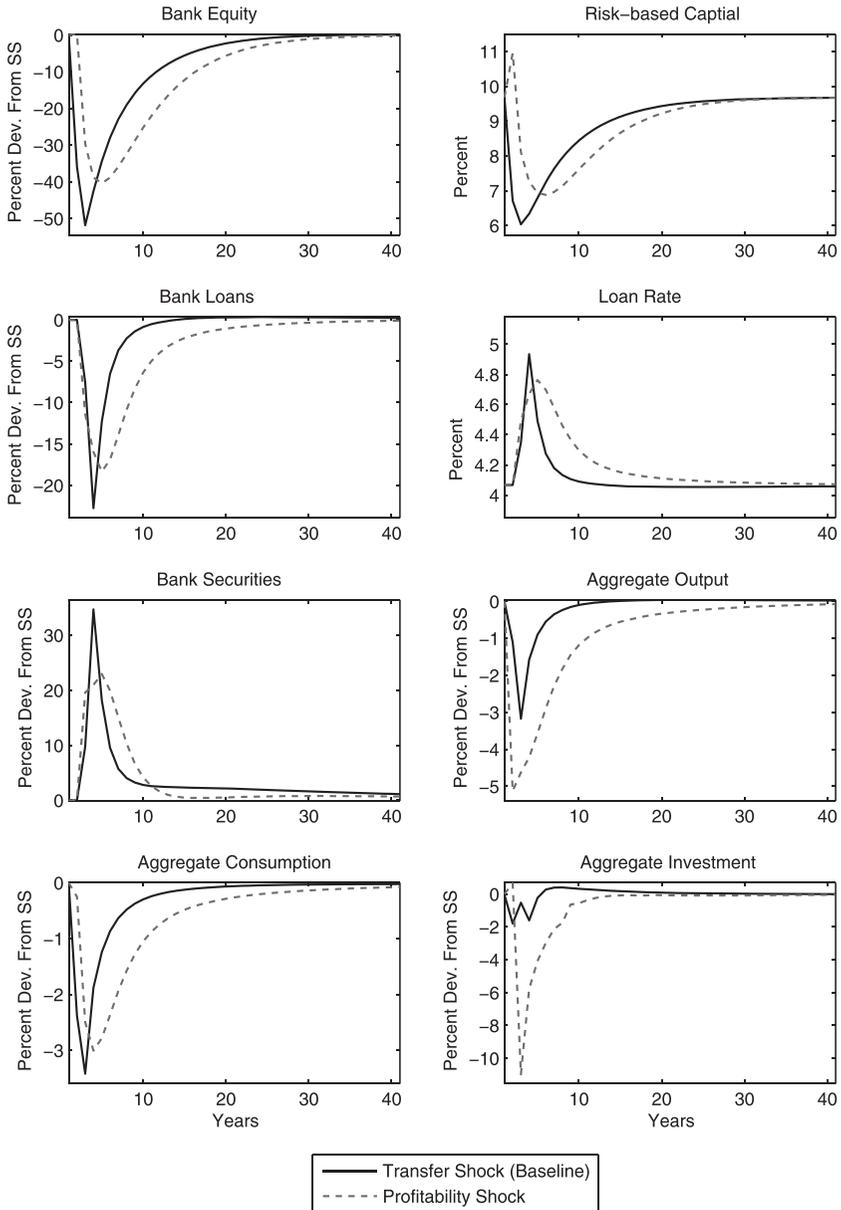
Finally, increasing the size of the capital requirement and requiring bankers to hold more equity prior to the transfer shock generates very similar responses in aggregate output and consumption relative to the baseline case. This suggests that the key mechanism in this model is driven by likelihood of banks to be capital constrained and not the level of equity held by banks. An important assumption in the model is that banks are not allowed to violate the capital requirement of 10 percent. Taken together, these two experiments suggest that allowing banks to go below the capital requirement at the same time the transfer shock occurs would yield sizable welfare gains relative to the case in which capital requirements are left unchanged.

4.4 Responses to an Alternative Shock Affecting the Balance Sheet of Banks

A final alternative looks at the effect of another shock: a reduction in bank revenues. In particular, we model the decrease in bank revenues by assuming a persistence shock to the non-interest component of bank revenues. Bankers are assumed to have perfect foresight of the shock. The shock is calibrated so that the change in wealth of bankers is roughly the same as the change of wealth induced by the transfer shock in the baseline calibration.

As seen in figure 6, the effect of the revenue shock reduces aggregate output by about 5 percent in the first year and 4.5 percent in the second year, which is considerably more than the response found above for the case of the transfer shock. This is not surprising since in this exercise bankers' wealth is no longer transferred to the entrepreneurial and workers' sectors. As a result, the reduction in output driven by the entrepreneurial sector is not partially offset by the increase in output in the corporate sector. Finally, consumption falls by substantially less—bottoming out at about a 3 percent reduction since bankers have perfect foresight of the shock and are able to smooth consumption more effectively.

Figure 6. Transfer Shock vs. Bank Revenue Shock in the Covas/Driscoll Model



Notes: Under the “Profitability Shock,” bank revenues decline following a persistent shock to the non-interest revenues. The transfer shock is sized so that the change in wealth of bankers is comparable to the change of wealth induced by the transfer shock.

5. Michael Kiley and Jae Sim: Intermediary Leverage, Macroeconomic Dynamics, and Macroprudential Policy

5.1 *Model Description*

Kiley and Sim (2013, KS below) study the nexus between macroprudential policy and monetary policy. To that end, Kiley and Sim develop a macroeconomic model in which the financial intermediaries mix debt and equity capital to finance their investments subject to financial frictions that make intermediary choice of capital structure deviate from the Miller-Modigliani theorem within an otherwise standard dynamic general equilibrium model of the type used in monetary policy analysis such as that found in Smets and Wouters (2007). Thus, the capital structure of intermediaries in KS is optimized to balance the benefits of leverage and the costs of bankruptcy under the costly recapitalization option rather than being imposed by a regulatory fiat, a feature that helps explain the role of an unregulated financial sector in the propagation of macroeconomic shocks. The description below sketches the main details of the model and its calibration.¹²

The model economy consists of (i) a representative household, (ii) a representative firm producing intermediate goods, (iii) a continuum of monopolistically competitive retailers, (iv) a representative firm producing investment goods, and (v) a continuum of financial intermediaries. A key assumption that makes the model's asset pricing implication in sharp contrast with that of frictionless neoclassical models is that the representative household lacks the knowledge needed to manage financial investments, and thus turns to the financial intermediaries that have special knowledge in selecting and managing financial projects but face financial friction in funding their operations. This delegation of investment function from a financially unconstrained agent to a constrained agent with limits of arbitrage makes the model's propagation mechanism of financial disturbances drastically different from that of

¹²A detailed description can be found in the online appendix.

frictionless business cycle models through the dynamics of pecuniary externality.¹³

The important role of liquidity condition of financial intermediaries in asset price dynamics can be seen in the following asset pricing equation of KS:

$$1 = \mathbb{E}_t \left\{ M_{t,t+1}^B \cdot \frac{1}{m_t} \left[\frac{\mathcal{R}_{t+1}^A}{\Pi_{t+1}} - (1 - m_t) \frac{R_{t+1}^B}{\Pi_{t+1}} \right] \right\}, \quad (8)$$

where $M_{t,t+1}^B$ is the intermediary pricing kernel, m_t is the capital ratio optimally chosen by the intermediaries, and $\mathcal{R}_{t+1}^A/\Pi_{t+1}$ and R_{t+1}^B/Π_{t+1} are intermediaries' real return on assets and borrowing rates. Equation (8) summarizes all the important deviations of the model from standard asset pricing models: (i) (8) is a levered asset pricing formula, and the *net* asset returns is scaled up by a factor $1/m_t$; (ii) the intermediary pricing kernel is a filtered version of the household's stochastic discounting factor, where the filter is due to the liquidity condition of the intermediaries measured by the ratio of shadow value of internal funds today versus tomorrow, i.e., $M_{t,t+1}^B = \mathbb{E}_{t+1}[\lambda_{t+1}|\Omega_{t+1}]/\mathbb{E}_t[\lambda_t|\Omega_t] \cdot M_{t,t+1}$, where $\mathbb{E}_t[\lambda_t|\Omega_t]$ measures the ex ante shadow value of internal funds based on all the available macroeconomic information (Ω_t); (iii) the return on asset deviates from the frictionless counterpart because, first, raising outside capital is costly due to dilution effects¹⁴ and thus lowers the effective return on equity, and second, the limited liability of financial intermediaries create a strictly positive value of default option, which then interacts with risk-taking of intermediaries.¹⁵

¹³A similar assumption also plays an important role in the majority of the recently developed macroeconomic models featuring intermediary funding constraints such as Brunnermeier and Sannikov (2014), Gertler and Karadi (2011), Gertler and Kiyotaki (2010), and He and Krishnamurthy (2012).

¹⁴Dilution costs arise when firms announce new offerings of seasoned equities and the announcement leads to a drop in the market value of existing shares. The dominant interpretation of the phenomenon in the literature is provided by Myers and Majluf (1984), who show that asymmetric information in capital markets may lead uninformed investors to discount the value of new shares to avoid *lemons*, which then causes the market value of existing shares to drop by arbitrage.

¹⁵In contrast to the majority of this literature, defaults of financial institutions are equilibrium outcomes. In this aspect, the model is akin to Brunnermeier and Sannikov (2014).

5.2 Calibration

The calibration of parameters regarding preferences and technology reflects conventional values. The constant relative risk aversion, habit formation, and the elasticity of labor supply are set equal to 3, 0.8, and 3, respectively, to be consistent with the micro-level evidence. The capital share of production function is set equal to 0.4. The quadratic adjustment cost of investment is chosen as 2. KS does not posit a utilization cost of capital and takes a constant depreciation rate of 0.025. The quadratic cost of price adjustment is set equal to 120. This choice is equivalent to a quarter fraction of firms resetting prices at any point in time given the steady-state markup of 1.11. Inflation indexation and wage rigidity are not considered for the transparency of the results. The monetary policy reaction function parameters are chosen as 1.5, 0.125, and 0.8 for inflation gap, production-based output gap, and monetary policy inertia, respectively (see the online appendix for details).

There are parameters associated with the long-run capital structure, dilution cost of equity issuance, corporate income tax shield, bankruptcy cost of failed institution, and idiosyncratic volatility. The dilution cost is set to 0.15 in the steady state, which is in the middle of the range reported in corporate finance literature. The tax differential between corporate and personal income tax rates is set to 0.20. Given all other parameters, the idiosyncratic volatility is chosen to match the 0.40 capital ratio, which facilitates the comparison with other papers in this literature. The bankruptcy cost is then specified as 3 percent of the size of the balance sheet to match the steady-state, short-term funding spreads.¹⁶

5.3 Impact of Balance Sheet Shock: Baseline Results and Robustness

To illustrate the importance of the intermediary liquidity position on macroeconomic outcomes, we consider a financial shock that transfers a certain amount of resources from financial intermediaries to

¹⁶All parameter values are broadly consistent with the original choices made in KS.

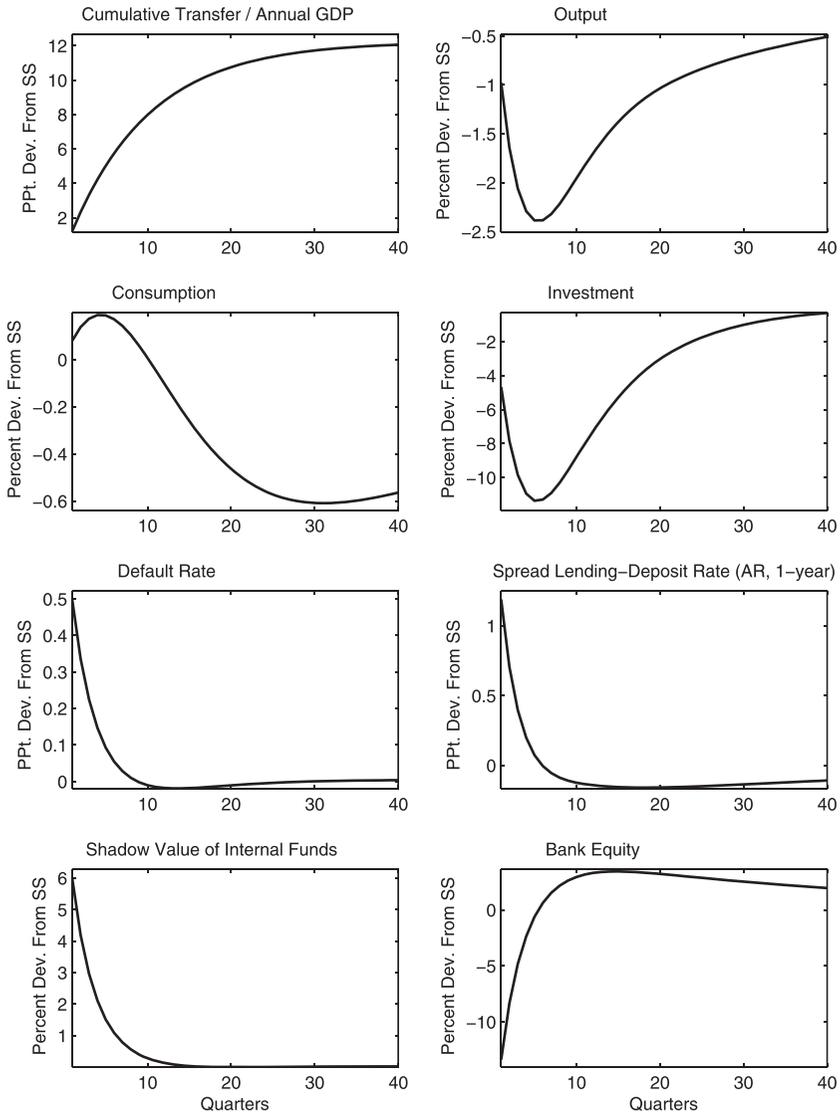
the representative household in a lump-sum fashion. This stylized shock helps highlight the role of financial market friction in the model since it does not directly affect the marginal productivity of physical capital in the economy and thus would have no impact on the allocation of real resources in a frictionless economy because, first, the investment decisions of the financial intermediaries are not affected by their liquidity condition, and second, the loss in the wealth of households due to the decline in the value of equities of financial institutions is exactly offset by the positive wealth transfer to households. The size and persistence of the shock follow the calibration choices discussed in section 2.

Figure 7 shows the impact of the shock on the real economy and financial markets. By construction, the shock does not have any impact if the financial friction in the model is taken out. However, as shown in the figure, the shock leads to a massive contraction in the real economy: maximum contraction on output, consumption, and investment amount to 2.5 percent, 0.6 percent, and 11 percent, respectively.

The reason for this strong reaction of the real economy can be found in the response of financial markets also shown in figure 7. On the impact, the default rate of intermediaries shoots up 0.5 percentage point. This is due to both the direct hit to the internal funding condition by the transfer shock and the indirect result of the endogenous decline in the asset prices. While the financial intermediaries try to raise outside capital as shown by the stiff increase in equity issuance, as much as 20 percent relative to its normal level, doing so in the KS model is costly due to a dilution cost. Finally, the increased cost of capital is passed through to the lending spreads, resulting in a large reduction in overall credit and a sizable contraction in economic activity.

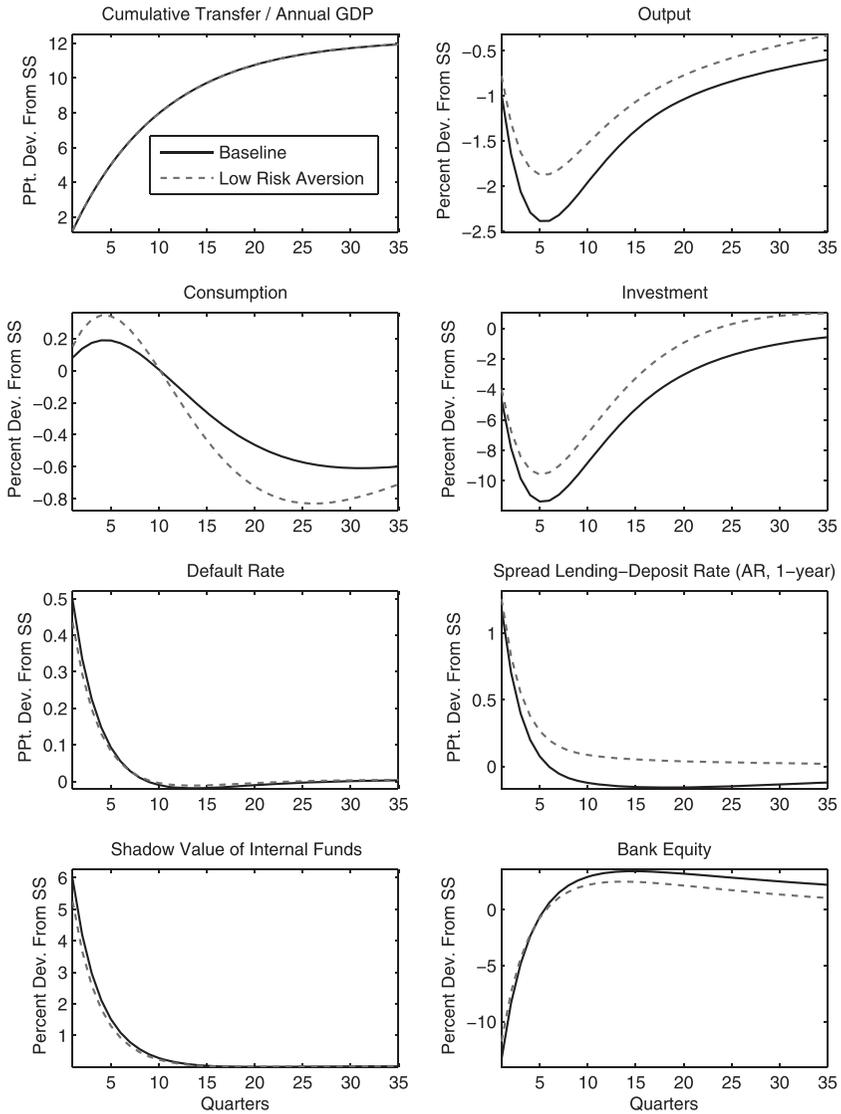
The results shown in figure 7 are sensitive to calibration choices. Among others, the relative risk aversion turns out to be very important in assessing the overall impact of the balance sheet transfer shock, as shown in figure 8. On impact, household consumption increases moderately, as a decline in household wealth, stemming from the reduced value of intermediary shares, is not perfectly offset by the transfer shock under the financial friction. This initial increase in consumption plays an important role in determining the overall size of the impact, as consumption accounts for about 80 percent of

Figure 7. Transfer Shock in the Kiley/Sim Model



total spending in the model. Having a lower degree of relative risk aversion makes the initial hump of household consumption bigger, reducing the size of overall impact on the economy. For instance, setting the parameter equal to 1 (log utility) reduces the maximum

**Figure 8. Transfer Shock in the Kiley/Sim Model:
Sensitivity Analysis**



Notes: Under the baseline calibration, the coefficient of relative risk aversion is set to 3. Under “Low Risk Aversion,” the coefficient of relative risk aversion is set to 1.

impact on the output to 2 percent, about 50 bps lower than what is shown in the figure.¹⁷

5.4 *Alternative Financial Shock: Dilution Cost Shock*

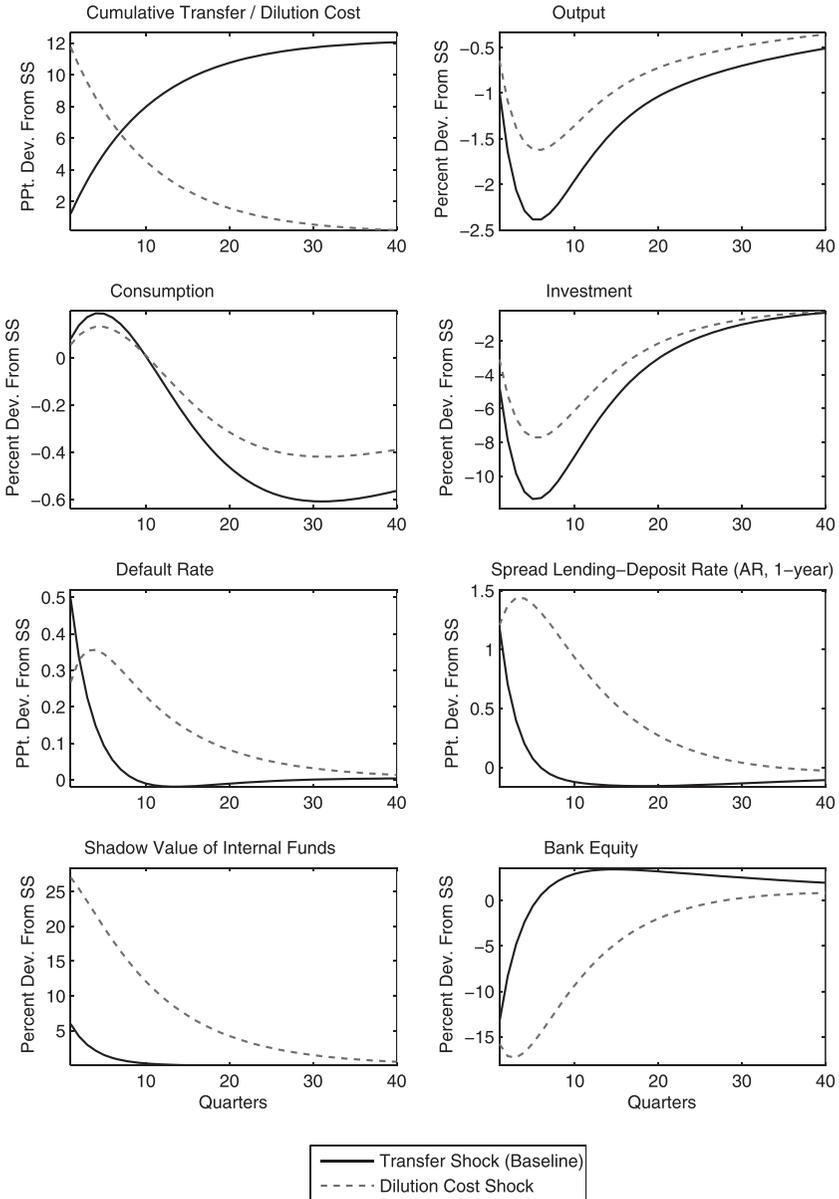
KS uses the balance sheet shock only as an illustration device. A financial shock that plays a more important role is a shock to the cost of raising outside equity—what we call a dilution cost shock. This shock has more desirable features in generating an economic crisis induced by stressed financial system. Financial stresses are usually associated with greater uncertainty, which can aggravate the asymmetric information in financial markets and lead to a greater lemon premium that elevates the cost of equity capital for financial intermediaries.

Figure 9 reports the impact of a dilution shock on the real economy and financial markets when calibrated to match the initial capital shortfall induced by the transfer shock. For ease of comparison, the persistence of the shock is set the same as in the transfer shock. As shown in the figure, the shock elevates dilution costs by a little less than 5 percentage points. The contour of the dynamic responses of real variables is broadly similar to those in the case of transfer shock.

While the peak impacts on output, consumption, and investment are about half the size of the peak impacts of the transfer shock, the shock and the propagation mechanisms appear empirically relevant. In contrast to the case of the transfer shock, equity issuance shows a hump-shaped response. Facing a greater cost of raising outside equity, the intermediaries can only gradually recapitalize in response to the shortfall in capital, which is, unlike in the case of transfer shock, entirely due to the endogenous fall in asset prices resulting from preemptive downsizing of intermediary balance sheets. As a

¹⁷The degree of nominal rigidity, and hence the flatness of the Phillips curve, is also important. For instance, halving the price adjustment cost to let the impact of the shock be absorbed by greater adjustment in prices reduces the maximum response of output by 30 bps. However, even with completely frictionless price setting, the maximum impact is reduced only by 60 bps. Finally, the size of investment adjustment friction also matters. While a greater adjustment friction in this sector increases the asset price volatility in general, it leads to a smoother response in aggregate investment and output. As a result, for instance, doubling the size of this friction can reduce the maximum impact on the output by 60 bps.

Figure 9. Effects of a Dilution Cost Shock vs. a Transfer Shock in the Kiley/Sim Model



Notes: The dilution shock raises the dilution costs by a little less than 5 percentage points. The shock is sized to match the initial capital shortfall induced by the baseline transfer shock.

consequence, the capital shortfall persists, and the resulting defaults and elevated funding costs persist as well, prolonging the downturn in a way consistent with recent experience.

6. Albert Queralto: Banks and Outside Equity

6.1 *Model Description*

The model of this section builds on recent papers that introduce financial intermediation in a business cycle framework—for example, Gertler and Karadi (2011) and Gertler and Kiyotaki (2010). These papers extend the basic financial accelerator mechanism developed by Bernanke and Gertler (1989) and Kiyotaki and Moore (1997) to financial intermediaries (banks) in order to capture a disruption of intermediation. In this class of models, banks borrow short-term non-contingent debt from depositors and use these funds (together with their own internal funds) to make loans to non-financial firms. As in the earlier literature on the financial accelerator, financial market frictions are endogenized by introducing an agency problem that potentially constrains the ability of banks to obtain funds from depositors. When the constraint binds, the balance sheets limit the ability of banks to obtain deposits. In this instance, the constraint effectively introduces a wedge between loan and deposit rates, which rises as the balance sheets of banks deteriorate. This raises the cost of credit that non-financial borrowers face. In this way, when banks are highly leveraged, adverse returns to their balance sheet may lead to sharp increases in credit spreads and declines in investment and economic activity.¹⁸

Key to motivating a crisis within these frameworks is the heavy reliance of banks on short-term debt. This feature makes these institutions highly exposed to the risk of adverse returns to their balance sheet in way that is consistent with recent experience. Within these frameworks and most others in this class, however, by assumption the only way banks can obtain external funds is by issuing short-term debt. Thus, in their present form, these models are not equipped to

¹⁸The full model description can be found in the online appendix accompanying this paper.

address how the financial system found itself so vulnerable in the first place.

In the model analyzed here, banks are allowed to issue outside equity as well as short-term debt.¹⁹ This feature makes bank risk exposure an endogenous choice, as outside equity allows banks to share risk with equity holders. The goal is to have a model that can not only capture a crisis when financial institutions are highly vulnerable to risk, but also account for why these institutions adopt such a risky balance sheet structure in the first place. Accordingly, the model extends the agency problem between banks and savers to allow intermediaries a meaningful tradeoff between short-term debt and equity. Ultimately, a bank's decision over its balance sheet will depend on its perceptions of risk. Thus, the model allows a quantitative analysis of the interplay between risk perceptions by banks, the liability structure that they choose, and the vulnerability of the economy to a crisis.

The production side of the model is analogous to a standard frictionless real business cycle (RBC) economy. The production function, capital accumulation, and resource constraint are as follows:

$$Y_t = AK_t^\alpha L_t^{1-\alpha}, \quad (9)$$

$$K_{t+1} = \psi_{t+1} [(1 - \delta)K_t + I_t], \quad (10)$$

$$Y_t = C_t + \left[1 + f \left(\frac{I_t}{I_{t-1}} \right) \right] I_t, \quad (11)$$

where Y_t , K_t , L_t , I_t , and C_t denote output, physical capital, labor, investment, and consumption, respectively. In (10), ψ_{t+1} is a capital quality shock, which serves as a trigger of movements in the quality of banks' assets. It can be thought of as capturing a form of economic obsolescence.²⁰

¹⁹The structure of the model closely follows Gertler, Kiyotaki, and Queralto (2012). See their paper for a complete description.

²⁰See the appendix of Gertler, Kiyotaki, and Queralto (2012) for a micro-foundation of the capital quality shock along these lines. This appendix is available as supplementary material at Elsevier's website: <http://www.journals.elsevier.com/journal-of-monetary-economics/>.

The preference structure follows Miao and Wang (2010), in turn based on Greenwood, Hercowitz, and Huffman (1988) (GHH hereafter). The preference specification allows for (internal) habit formation and, as in GHH, abstracts from wealth effects on labor supply. The household’s problem is as follows:

$$\max \quad \mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \frac{1}{1-\gamma} \left(C_{\tau} - hC_{\tau-1} - \frac{\chi}{1+\varphi} L_{\tau}^{1+\varphi} \right)^{1-\gamma},$$

subject to

$$C_t + D_{h,t} + q_t e_t = W_t L_t + \Pi_t - T_t + R_t D_{h,t-1} + [Z_t + (1-\delta)q_t] \psi_t e_{t-1}. \tag{12}$$

Note that the household has access to non-contingent riskless short-term debt (deposits), denoted $D_{h,t}$ and paying gross interest R_t , as well as bank (outside) equity, e_t .²¹ The price of a unit of outside equity is q_t , and Z_t denotes the flow returns at t generated by one unit of the bank’s assets. The units of outside equity are normalized so that each unit is a claim to the future returns of one unit of the asset held by the bank.

Each bank raises funds by issuing deposits d_t and outside equity to purchase producers’ equity, s_t , at price Q_t :

$$Q_t s_t = n_t + q_t e_t + d_t. \tag{13}$$

The evolution of a bank’s net worth (or inside equity), n_t , is as follows:

$$n_t = [Z_t + (1-\delta)Q_t] \psi_t s_{t-1} - [Z_t + (1-\delta)q_t] \psi_t e_{t-1} - R_t d_{t-1} - \xi_t. \tag{14}$$

Above, ξ_t is a capital transfer which subtracts from the bank’s resources at the beginning of the period. It is assumed to be taken from the bankers and given to the households, and therefore only has effects insofar as net worth constrains banks’ ability to obtain

²¹Outside equity refers to equity issued by banks and held by households, while inside equity (or net worth) refers to the accumulated retained earnings of a banker who manages an intermediary.

funds. Accordingly, in the RBC version of the model, the effects of the transfer are nil, as it is just a redistribution of wealth within the representative household.

From equation (14), note that the use of outside equity reduces the impact of return fluctuations on net worth. When e is higher, movements in returns to the bank's assets are passed on to outside equity holders (households) to a greater extent, thus acting as a hedge. By contrast, deposit financing is risky for the bank, since its cost is non-contingent. In our quantitative analysis, we interpret outside equity as capturing securities that allow banks to share risk with the security holders broadly. In particular, we assume that outside equity in the model corresponds to common equity, while inside equity, n , corresponds to the sum of preferred equity and subordinate debt. We calibrate the parameters of the model so that the ratio of outside to inside equity in the steady state equals two-thirds, which roughly matches the U.S. banking sector prior to the crisis.

The value of the bank at the end of period t is

$$V_t = V(s_t, x_t, n_t) = \mathbb{E}_t \sum_{\tau=t+1}^{\infty} (1 - \sigma) \sigma^{\tau-t} \Lambda_{t,\tau} n_{\tau}, \quad (15)$$

where $x_t = \frac{q_t e_t}{Q_t s_t}$, and σ is the banker's survival probability. After obtaining funds, the banker may default on debt and divert a fraction $\Theta(x_t)$ of assets. The incentive constraint for the bank not to steal is

$$V(s_t, x_t, n_t) \geq \Theta(x_t) Q_t s_t. \quad (16)$$

The divertable fraction is a convex function of x_t :

$$\Theta(x_t) = \theta \left(1 + \epsilon x_t + \frac{\kappa}{2} x_t^2 \right). \quad (17)$$

We assume that the amount divertable is increasing in the degree of outside equity x_t , and therefore the constraint of the bank is tighter the larger is x_t .²² This represents a cost of outside equity which the bank trades off against its hedging benefit.

²²The idea is that short-term deposits give banks less discretion over payouts than equity, and therefore offer more discipline over bank managers than does outside equity. This idea is due to Calomiris and Kahn (1991).

Table 3. Calibrated Parameters in Queralto’s Model

γ	2	Risk Aversion
β	0.99	Discount Factor
α	0.33	Capital Share
δ	0.025	Depreciation Rate
χ	0.25	Utility Weight of Labor
φ	1/3	Inverse Frisch Elasticity of Labor Supply
If''/f'	1	Inverse Elasticity of Investment to the Price of Capital
h	0.75	Habit Parameter
σ	0.9685	Survival Rate of Bankers
ξ	0.0289	Transfer to Entering Bankers
<i>Asset Diversion Parameters</i>		
θ	0.264	
ε	-1.21	
κ	13.41	

6.2 Calibration and Model Solution

Table 3 reports the baseline parameter values. The preference and technology parameters are set to reasonably conventional values. The banking-sector parameters are chosen to match salient features of the U.S. financial intermediation sector.

In the model, bank balance sheet structure depends on risk perceptions. It is thus important to take risk into account in the computation of the model. Similar to Coeurdacier, Rey, and Winant (2011), a “risk-adjusted” steady state is constructed, where given agents’ perceptions of second moments, variables remain unchanged if the realization of the (mean-zero) exogenous disturbance is zero. The risk-adjusted steady state differs from the non-stochastic state only by terms that are second order. These second-order terms, which depend on variances and covariances of the endogenous variables, pin down banks’ balance sheet. Model dynamics are then analyzed by computing a first-order log-linear approximation around the risk-adjusted steady state.

To calculate the relevant second moments, we use an iterative procedure. We first log-linearize the model around the non-stochastic

steady state. We then use the second moments calculated from this exercise to compute the risk-adjusted steady state. We repeat the exercise, this time calculating the moments from the risk-adjusted steady state. We keep iterating until the moments generated by the first-order approximation around the risk-adjusted steady state are consistent with the moments used to construct it.²³

6.3 *Transfer Shock*

Figure 10 plots a dynamic simulation of the model economy following a transfer shock. Here the amount of exogenous volatility is calibrated as the average between a low-risk economy (meant to reproduce the Great Moderation period) and a high-risk economy (which captures the period of volatility in the two decades prior to the Great Moderation). The idea is that the aftermath of the Global Financial Crisis is characterized by heightened uncertainty relative to the Great Moderation, but risk is still not as high as in the high-volatility period of the 1960s and 1970s. The size and persistence of the transfer shock follow the calibration choices discussed in section 2.

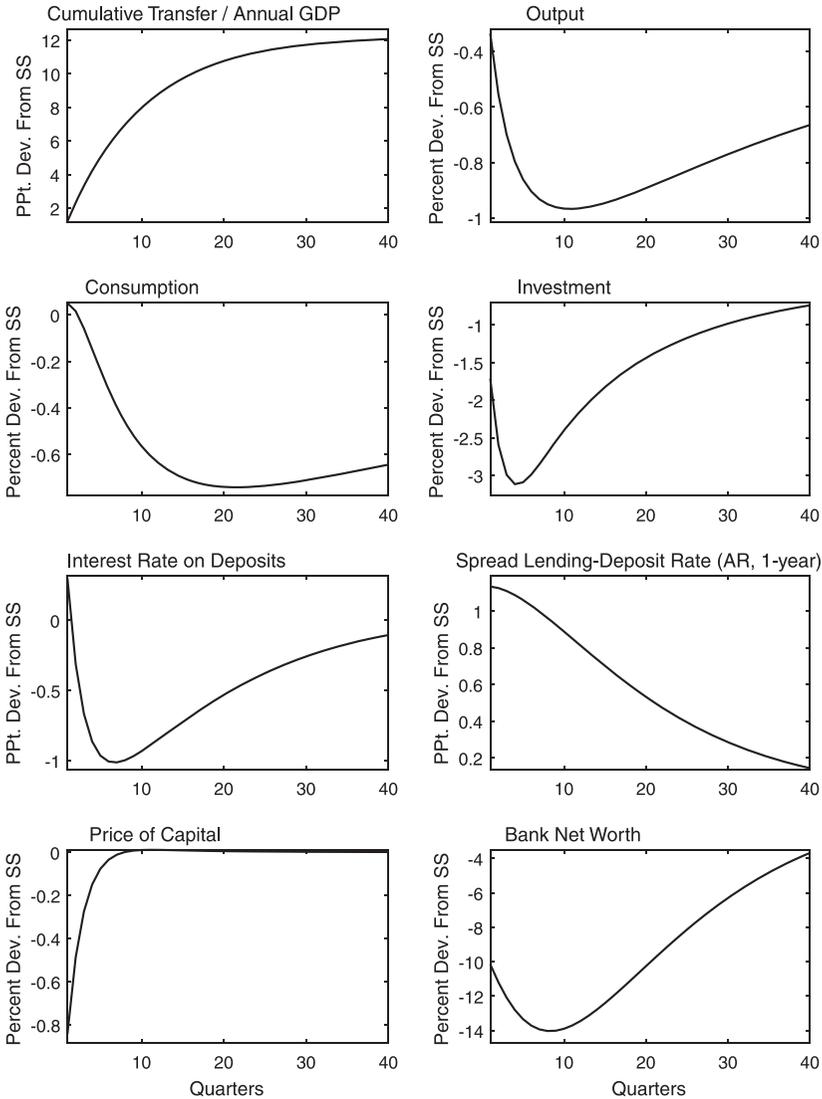
The loss in capital in the intermediation sector worsens the agency problem between banks and their creditors, leading the credit spread to rise by more than 100 basis points. With their balance sheets impaired, banks' ability to lend is diminished, and aggregate investment and asset prices drop as a result. Along the way, the financial accelerator mechanism operates, as drops in bank net worth and in the asset price Q_t reinforce each other. All told, output falls by about 1 percentage point, and investment drops by more than 3 percentage points.

6.4 *Robustness Analysis*

Several authors have suggested that the low volatility during the Great Moderation period may have induced a sense of complacency about risk in financial markets, which ultimately contributed

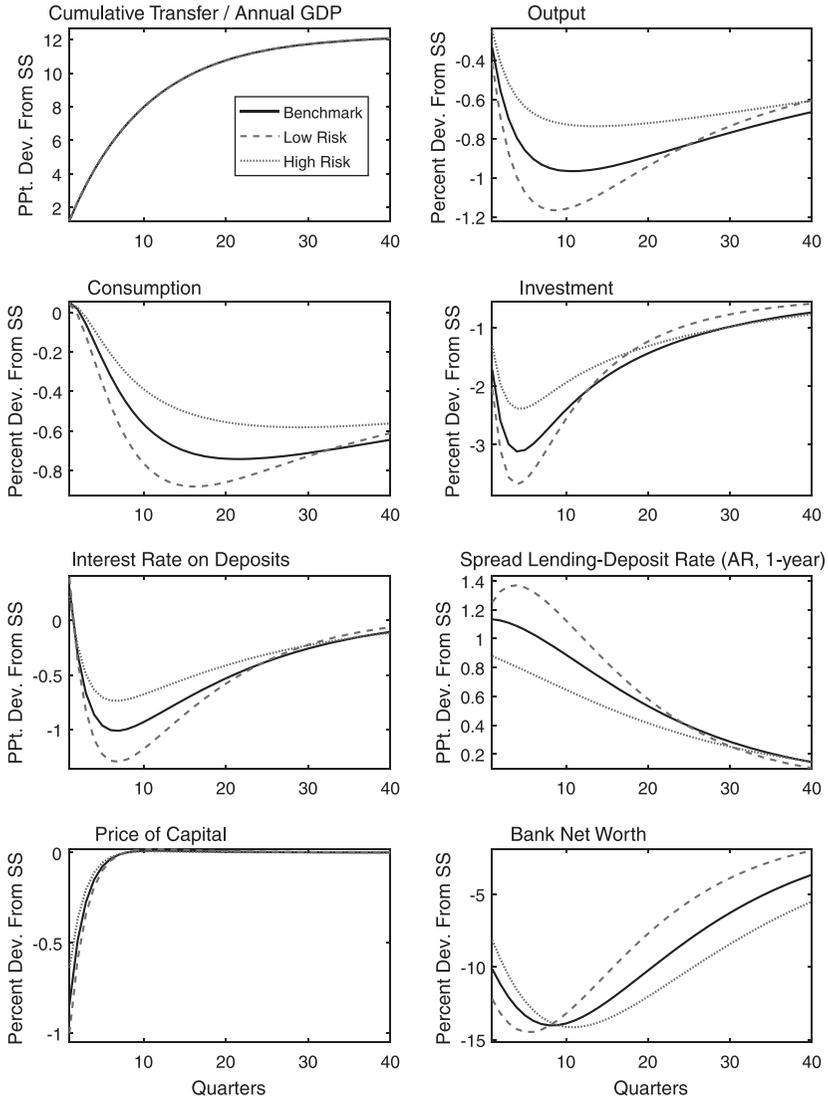
²³See the appendix of Gertler, Kiyotaki, and Queralto (2012) for details.

Figure 10. Transfer Shock in Queraltó's Model



to the vulnerability of the system once the crisis hit. To illustrate this possibility, figure 11 performs robustness analysis by modifying the level of exogenous risk. The low-risk economy features standard deviations of the shock processes so that the standard deviation

**Figure 11. Transfer Shock in Queralto’s Model:
Sensitivity Analysis**



Notes: “Low Risk” refers to an economy in which the standard deviation of the exogenous capital quality shock is 0.69 percent. In the “High Risk” economy, the standard deviation of the capital quality shock equals 2.07 percent. For ease of comparison, “Benchmark” reports again the results for the benchmark calibration of the Queralto model that sets the standard deviation of the capital quality shock at an intermediate value.

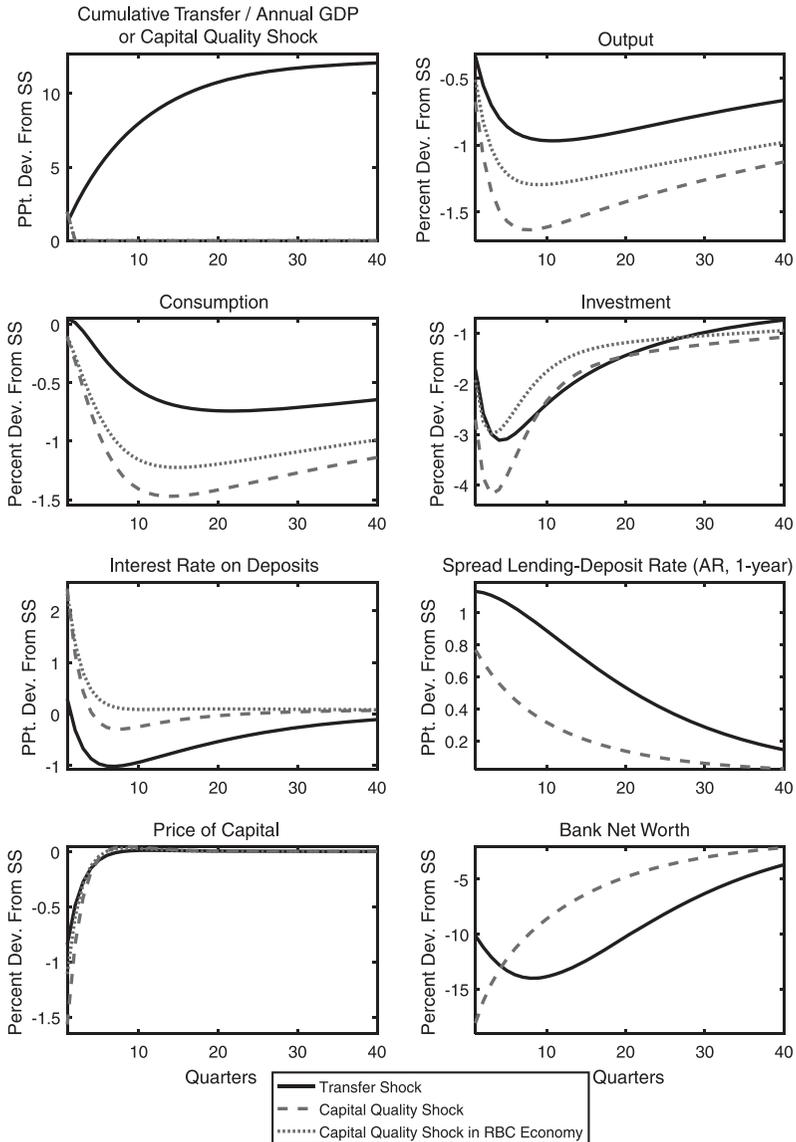
of annual output growth corresponds roughly to that in the Great Moderation period, while the high-risk economy features a level of risk corresponding to the period of volatility in the two decades prior.

When risk is high, the effects of the shock are weaker, and with low risk the effects are stronger. The reason is straightforward: the anticipation of high risk induces banks to substitute outside equity for short-term debt, as higher risk increases the hedging value of outside equity. When the shock hits, outside equity acts as a buffer in two ways. First, it moderates the drop in inside equity induced by the decline in asset values. Second, as the effects of the shock unfold after the initiating disturbance, banks are able to relax their borrowing constraint a bit by substituting short-term debt for outside equity (recall that short-term debt permits creditors greater discipline over bankers).

The differences in exogenous risk lead to quantitatively significant differences in the effects of the transfer shock. When risk is high, the peak decline in investment moderates from over 3 percent in the baseline case to a little above $2\frac{1}{4}$ percent, and the peak output loss is less than $\frac{3}{4}$ percent, compared with about 1 percent in the baseline case. Conversely, when exogenous risk is low—leading banks to adopt a more risky balance sheet structure—investment drops $3\frac{3}{4}$ percent at its trough. The drop in output reaches nearly $1\frac{1}{4}$ percent.

Figure 12 compares the effects of the transfer shock (in the low-risk economy) with those of a decline in capital quality, where the magnitude of the latter is calibrated to induce the same average decline in bank net worth as the transfer shock over the five years following the shock. The effects of the capital quality shock are considerably larger, leading output to drop more than 2 percent at the trough. The reason is that the decline in capital quality effectively leads to a reduction in the amount of physical capital in the economy, and therefore has adverse effects even in an economy with no financial frictions, as indicated by the dotted line. On the other hand, the degree of financial-sector spillovers (i.e., the contraction over and above what would happen in a frictionless economy) is comparable across the two shocks (recall that the transfer shock is only a redistribution of resources within the representative household, and therefore has no effects in a frictionless economy).

Figure 12. Transfer Shock vs. Capital Quality Shock in Queralto’s Model



Notes: “Capital Quality Shock” denotes the responses to a capital quality shock for the benchmark calibration of the Queralto model. The size of the shock was chosen to match the evolution of bank net worth, on average, over the first nine quarters with the effects of the transfer shock—reported again for ease of reference. The figure also shows a capital quality shock in a frictionless RBC economy.

7. Luca Guerrieri and Mohammad Jahan-Parvar: Capital Shortfalls in a Two-Sector Production Economy

7.1 *Model Description*

Guerrieri and Jahan-Parvar consider the effects of sectoral and aggregate financial shocks in a two-sector model. Firms in one sector have access to equity markets, while firms in the other sector can only finance capital purchases through credit extended by financial intermediaries (hereafter, banks, for short). The interactions of these two types of firms can buffet the macro effects of shocks that reduce the equity position of banks. The demand for capital by equity-financed firms acts to curb equilibrium movements in the price of capital which otherwise amplifies the macro response to variation in credit from the banking sector. However, aggregate valuation shocks that affect both equity markets and banks continue to have sizable macro repercussions. Apart from sensitivity analysis relative to the size of the credit-dependent sector, the results highlight the implication of the zero lower bound on policy interest rates for the transmission of the baseline transfer shock.

The model is an extension of Gertler and Karadi (2011), hereafter abbreviated as GK. The extension is that not all firms are dependent on bank credit. Firms in the equity-financed sector are able to write a financing contract directly with households. A special case of the model with all firms financed by household equity reproduces the one-sector model considered by Boldrin, Christiano, and Fisher (2001). In the model, final goods are a Cobb-Douglas composite of goods produced by firms that are credit dependent and by firms that are equity financed. A retail sector purchases the intermediate goods and repackages them for consumers in a way that supports the inclusion of nominal rigidities. Monetary policy follows an interest rate reaction function that responds to current inflation and allows for interest rate smoothing. Production subsidies, in the absence of financial frictions, reproduce the efficient allocations in steady state. The description that follows highlights the credit-related friction but leaves the full description of the model for the online appendix.

The key financial friction for bank-dependent firms follows Gertler and Karadi (2011). Banks lend funds obtained from

households to non-financial firms. Let $N_t(j)$ be the amount of wealth—or net worth—that a banker j has at the end of period t .

$$Q_t S_t^b(j) = N_t(j) + D_t(j) \quad (18)$$

Deposits $D_t(j)$ pay a return $(1 + R_t)$ at time $t + 1$. Thus $D_t(j)$ may be thought of as the debt of bank j , and $N_t(j)$ as its capital. Credit extended to firms $S_t^b(j)$ earns the stochastic return $(1 + R_{t+1}^{bs})$ at time $t + 1$. Over time, the capital of banks evolves as the difference between earnings on assets and interest payments on deposits:

$$N_{t+1}(j) = (1 + R_{t+1}^{bs})Q_t S_t(j) - (1 + R_t)D_t(j). \quad (19)$$

Because banks may be financially constrained, they have an incentive to retain earnings, but bank capital does not expand indefinitely, because bankers cease operations with iid probability $1 - \theta$ each period. Upon exiting, a banker becomes a worker and all retained earnings are transferred back to his original household. Each period, a fraction $1 - \theta$ of all workers is selected to join the existing bankers and receives a startup transfer, so that the fraction of household members acting as workers and bankers is constant over time.

The objective of bank j is to maximize expected terminal wealth, given by

$$\begin{aligned} \max_{S_{t+i}^b(j)} V_t(j) = E_t \sum_{i=0}^{\infty} (1 - \theta)^i \psi_{t,t+1+i} & \left[(R_{t+1+i}^{bs} - R_{t+i}) Q_{t+i} S_{t+i}^b(j) \right. \\ & \left. + (1 + R_{t+i}) N_{t+i}(j) \right], \end{aligned} \quad (20)$$

where $\psi_{t,t+1+i}$ is the stochastic discount factor of households.

An agency problem limits the ability of banks to attract deposits. At the beginning of each period, a banker can choose to transfer a fraction λ of assets (in period t those assets equal $Q_t S_t(j)$) back to his household. If the banker makes the transfer, depositors will force the bank into bankruptcy and recover the remaining fraction $1 - \lambda$ of assets. Thus, households are willing to make deposits only if the incentive-compatibility constraint is satisfied:

$$V_t(j) \geq \lambda Q_t S_t(j). \quad (21)$$

When solving the model with a standard first-order perturbation solution, we assume that this constraint binds always with equality.

The setup of GK is nested and is reproduced when the share of equity-financed firms in production is zero. The model departs from GK along a few dimensions. Notably, unlike in GK, capacity utilization is constant; monetary policy responds only to inflation and to a lag of the monetary policy rate, and does not attempt to stabilize output around its steady-state value; the Frisch elasticity of labor supply is set to one, at the upper range of micro estimates, but well below the elasticity in GK. In the two-sector model, the equity- and credit-dependent firms produce intermediate goods that are necessary to produce an undifferentiated final good using a Cobb-Douglas production function. The sectoral shares are set to 0.5. A retail sector produces differentiated goods that are subject to nominal rigidities.²⁴

7.2 Baseline Shock and Comparisons with One-Sector Model

Figure 13 shows the effects of the baseline transfer shock from banks to households in our two-sector model. The shock is calibrated as discussed in section 2. The macro effects of the shock are modest. The drop in aggregate output grows in magnitude over two years to a peak of 0.45 percent of its steady-state value. The modest size of the spillover effects of the shock is related to the fact that the reduction in the demand for capital by credit-dependent firms is compensated by an increase in demand from the equity-financed firms.

As shown in figure 14, the macro spillover effects of the baseline transfer shock are greatly amplified in a one-sector model in which all firms are credit dependent. The main reason for this amplification is that lack of access to alternative funding leads to a large reaction in the equilibrium price of capital. In turn, in the one-sector model, the drop in the price of capital boosts the magnitude of the drop in bank capital and leads to a further curtailing of credit supply. By contrast, in a two-sector model, the price of capital barely responds to a transfer shock. Higher demand for capital from equity-financed firms acts to reduce downward pressures on the equilibrium price

²⁴Notice that when either $\lambda = 0$ or when all firms are equity financed, a monetary policy rule that stabilizes inflation would reproduce the allocations chosen by the benevolent planner.

Figure 13. Transfer Shock in Guerrieri/Jahan-Parvar Model

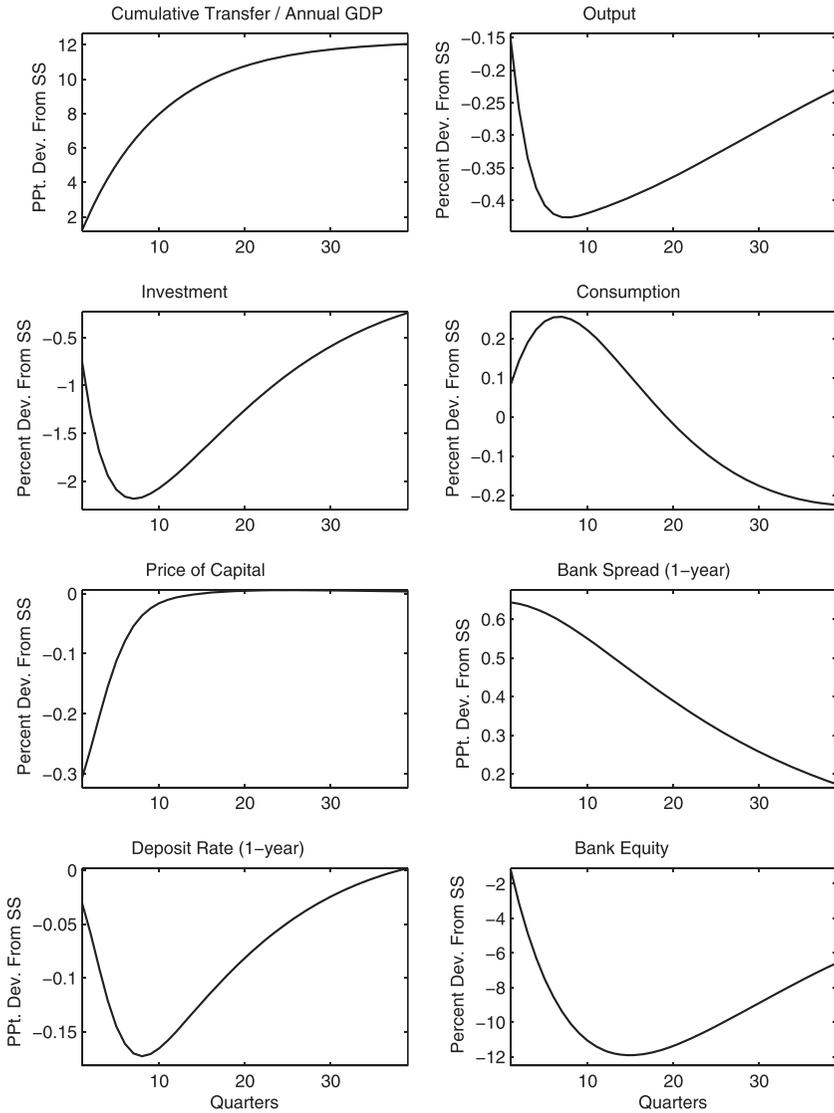
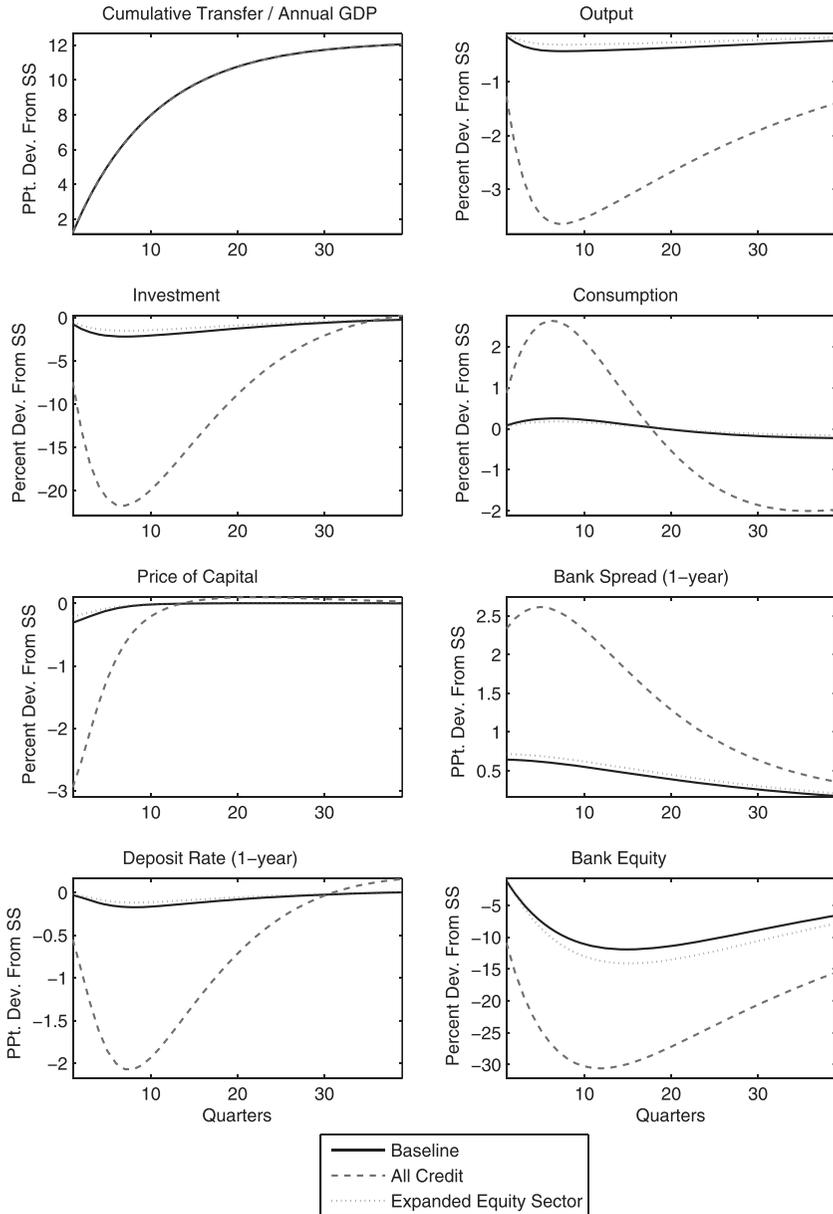


Figure 14. Transfer Shock in the Guerrieri/Jahan-Parvar Model: Sensitivity Analysis



Notes: The line denoted “All Credit” refers to a one-sector model in which all firms are credit dependent. Under “Expanded Equity Sector,” firms with access to equity financing account for 75 percent of aggregate output.

of capital. This stability in the price of capital has one principal implication—it reduces the endogenous response of bank equity to the exogenous transfer shock.

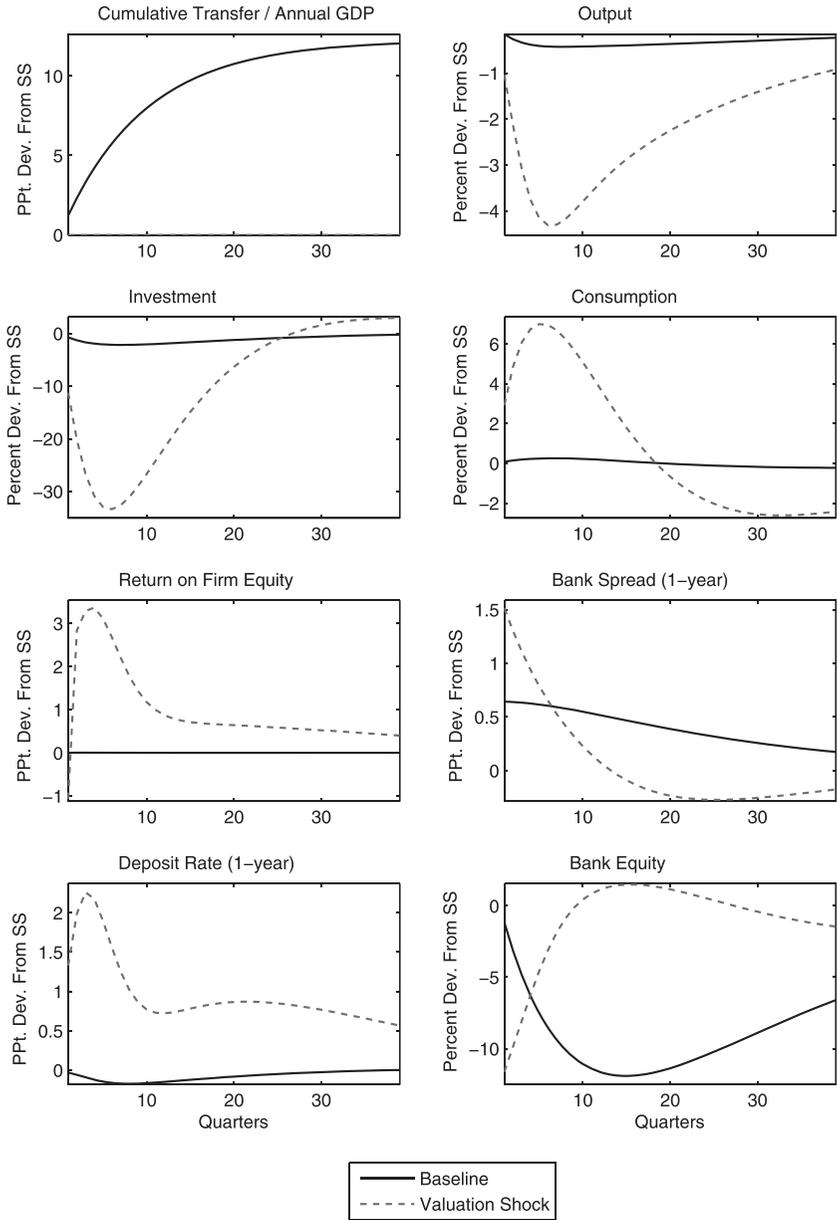
7.3 Sensitivity Analysis: The Response to an Economy-Wide Shock

The benchmark model introduced in section 7.2 focuses on a sector-specific shock whose aggregate effects are buffeted by the reaction of the other sector. This section considers the implications of an economy-wide valuation shock, following Albuquerque, Eichenbaum, and Rebelo (2012). Accordingly, the discount factor of households drops and the risk-free interest rate increases. The size of the shocks is set to match the average *endogenous* shortfall in bank capital from the baseline transfer shock (taking into account the equilibrium response of capital prices) over the first nine quarters.

Figure 15 reports the comparison of the impact of a valuation shock with that of a transfer shock in the baseline two-sector model. In this case, the macro effects of a financial shock are much closer to those that obtain in the special case of one-sector model in which all firms are credit dependent. Similar to GK and in contrast to the benchmark model, an economy-wide shock can cause a significant drop in output and investment. Since households own all the assets in the economy, a shock that lowers the discount factor implies less appetite for risk and a reduction in the funds available to both equity-financed firms and banks. The aggregate nature of the valuation shock dampens the role played by the equity-financed firms in counterbalancing the shocks to banks in the benchmark model. Accordingly, the equilibrium loan rate rises to compensate the shortage of available funds, resulting in a large drop in investment. Similar to GK, the macro spillovers of the financial shocks are amplified by a fall in the price of capital.

The benchmark model implies that the presence of additional financial assets issued by firms that are capable of direct intermediation with the households can mitigate the impact of a financial shock to banks. However, shocks that affect both equity- and credit-financed firms still lead to sizable macro spillover effects comparable to those that obtain in a one-sector model with all firms

Figure 15. Transfer Shock vs. Valuation Shock in Guerrieri/Jahan-Parvar Model



Notes: The line denoted “Baseline” shows the effects of the transfer shock under the baseline calibration. The line denoted “Valuation Shock” shows the effects of a shock that leads to a revaluation of bank equity that matches the drop in bank equity from the baseline transfer shock, on average, over the first nine quarters.

credit dependent. The analysis also highlights that shocks that have comparable impacts on the equity position of banks can have dramatically different macro spillover effects.

7.4 *The Response to the Baseline Transfer Shock at the Zero Lower Bound*

We revisit this amplification for the baseline transfer shock in our two-sector model against a deep recession that brings the economy to the zero lower bound. In the model, the deposit contract between banks and households is tantamount to an indexed bond with maturity equal to one quarter. In normal times, the real return on deposits hews closely to the nominal deposit rate and to the monetary policy rate. However, at the zero lower bound there can be a decoupling between the real return on deposits and nominal short-term interest rate.

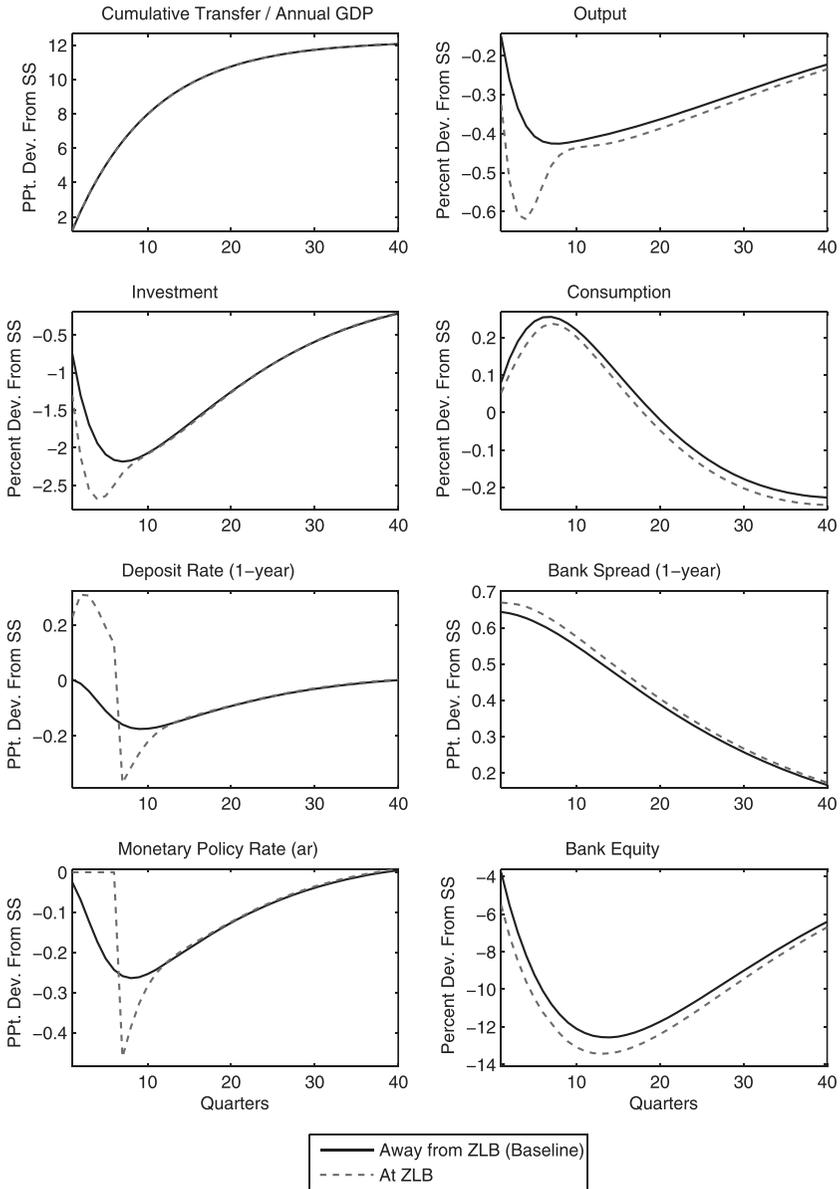
The stylized shock that leads the economy to the zero lower bound is a shock to preferences. The utility function of the representative household is modified as follows:

$$U_t = E_t \sum_{i=0}^{\infty} \beta^i \left[\log(C_{t+i} - \gamma C_{t+i-1} + \epsilon_{ct}) - \frac{\chi}{1+\epsilon} L_{t+i}^{1+\epsilon} \right], \quad (22)$$

where, again, C_t denotes consumption of final goods, and L_t denotes hours worked. The term ϵ_{ct} is a shock to consumption preferences. The shock itself is assumed to follow an autoregressive process of order 1, with a persistence coefficient equal to 0.7. The shock is sized so that households expect the policy interest rate to remain at the zero lower bound for six quarters in the absence of additional shocks. For the purpose of this section, the model is solved using a piecewise linear solution technique as developed by Guerrieri and Iacoviello (2015). As shown in Bodenstein, Erceg, and Guerrieri (2009), the particular mix of shocks that leads to recession and the attainment of the zero lower bound have a role in determining the marginal effects of additional shocks that is well summarized by the expected duration of the zero lower bound.

Figure 16 shows the effect of the transfer shock from banks to households under two configurations. In one case the transfer shock

Figure 16. Transfer Shock at the Zero Lower Bound in Guerrieri/Jahan-Parvar Model



Notes: The line denoted “Away from ZLB (Baseline)” shows the effects of the transfer shock under the baseline calibration, away from the zero lower bound on nominal interest rates. The line denoted “At ZLB” shows the effects of the transfer shock at the zero lower bound on nominal interest rates.

occurs against the background of a deep recession and the responses are shown in deviation from the outlook for the economy that agents expected prior to the realization of the transfer shock. In the other case, the responses are shown in deviation from their steady-state values (interpreted as “normal times” given the linear approximation used to solve the model).

Since banks cannot attract deposits at negative nominal rates, in the face of deflationary shocks, such as the transfer shock considered, the real return on deposits *rises* instead of falling. The unexpected rise in real deposit rate, equal in size but opposite in sign to the response of inflation in deviation from baseline, amplifies the drop in bank equity relative to normal times. In turn, the further drop in bank equity amplifies the rationing of credit and the contraction of investment and output relative to normal times, away from the zero lower bound.

It is well understood that the amplification of the responses of the economy to contractionary shocks in a liquidity trap is driven by the evolution of inflation expectations. In the model, the deflationary effects of the shock are kept to a relatively modest size—inflation drops $\frac{1}{4}$ percentage point at its nadir—principally by monetary policy. The policy rule is anticipated to respond aggressively to stabilize inflation away from the zero lower bound. The credible response of monetary policy away from the zero lower bound provides forward guidance. By contrast, with a less aggressive monetary policy rule, inflation is more volatile and the zero lower bound would amplify the effects of contractionary shocks in a more pronounced fashion. Similarly, the expected duration of the zero lower bound is a key determinant of the non-linear amplification effects at the zero lower bound. For an extended discussion of these issues see Bodenstein, Erceg, and Guerrieri (2009) and Bodenstein, Guerrieri, and Gust (2013).

8. Horizontal Comparison of Results

Table 4 summarizes the choices available to financial intermediaries that are salient in the reaction to a capital shortfall. The

Table 4. Model Characteristics

	Iacoviello	Covas/Driscoll	Kiley/Sim	Queralto	Guerrieri/ Jahan-Parvar
Choices Available to Banks:					
Issue New Equity	No	No	Yes	Yes	No
Reduce Dividend Payments	Yes	Yes	Yes	No	No
Increase Operating Efficiency	No	No	No	No	No
Raise Interest Spread	Yes	Yes	Yes	Yes	Yes
Increase Non-interest Income	No	No	No	No	No
Services Offered by Banks:					
Liquidity Provision	Yes	Yes	Yes	Yes	Yes
Liquidity Transformation	No	No	No	No	No
Other Features of the Model:					
Multiple Sources of Funding*	Yes	Yes	No	No	Yes
Nominal Rigidities	No	No	Yes	No	Yes
Solution Method	1st Order	Non-linear	1st-2nd Order	1st Order	Piecewise Linear

*"Multiple Sources of Funding" refers to the presence of sources of funding other than bank credit.

summary hews closely to the action set available to banks in reaction to changes in capital requirements, as summarized in an interim report of the BIS Macroeconomic Assessment Group (BCBS 2010). In addition to issuing new equity and to increasing retained earnings, the BIS report highlights that banks may in fact attempt to increase risk-weighted assets by shifting balance sheet composition towards less risky assets in ways not captured by any of the models presented here. Another feature not captured by any of the models presented is the possibility that banks could speed up the recapitalization process by increasing fees or, more generally, other sources of non-interest income. The table highlights that the models presented do in fact expand a core framework in complementary directions. Nonetheless, one source of homogeneity across models is that the financial sector is engaged in liquidity provision, and not in liquidity transformation, which could contribute to understating the macroeconomic repercussions of financial shocks.

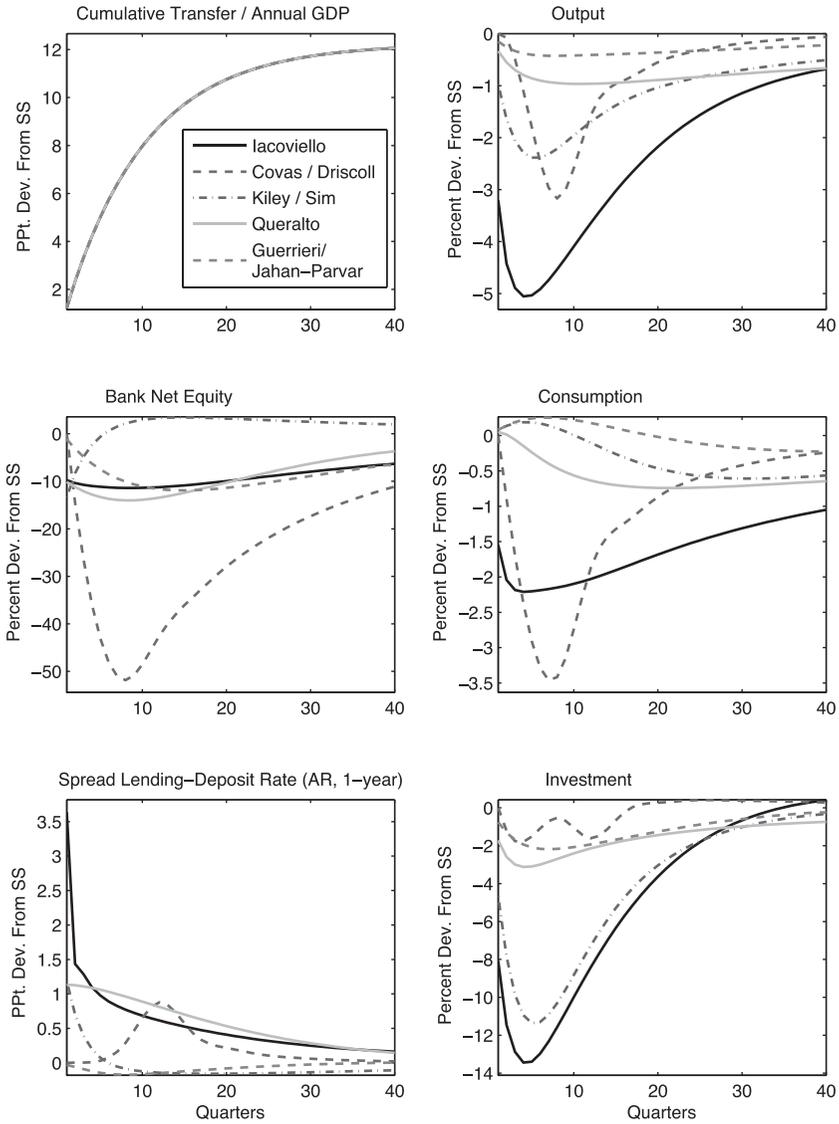
Figure 17 provides a horizontal comparison of the effects of the baseline transfer shock across models. The responses shown are in deviation from each model's steady state.²⁵ For completeness, table 5 reports key steady-state values for each of the models.

As shown in the top-left panel of the figure, the size of the transfer shock is standardized.²⁶ Despite the standardization of the cumulative transfer, the hit to bank equity across models differs greatly.

²⁵This approach hews closely to actual practice in several model comparison exercises in the literature: see, e.g., the work in Wieland et al. (2012) and references therein, which mostly compares model dynamics in deviation from each model's respective steady state. Steady-state comparisons could be useful to study, but, in keeping with common practice, we do not attempt to do so here. Our approach follows the common practice at many central banks that typically separates the construction of the baseline outlook from the construction of scenarios around the baseline outlook itself. Often, a common baseline is constructed using a combination of large-scale models, nowcasting, and judgmental projections. However, the scenarios are routinely constructed using a diverse set of models, where each model response is constructed in deviations from each model's baseline, and only later added to the common baseline.

²⁶Notice that to facilitate the comparison of the results of the model of Covas and Driscoll, calibrated at a yearly frequency, we have interpolated the model's responses to quarterly frequency using splines.

Figure 17. Horizontal Model Comparison



Notes: The figure shows responses to the baseline transfer shock (whose calibration is described in section 2) across all the models of the sections from 3 to 7 using the baseline calibration of each model. For ease of comparison, the responses for the yearly model of Covas and Driscoll were interpolated to quarterly frequency using splines.

Table 5. Steady-State Values for Selected Model Variables

Variable	Iacoviello	Covas/Driscoll	Kiley/Sim	Queralto	Guerrieri/ Jahan-Parvar
Ratio of Consumption to Output	0.75	0.7	0.81	0.78	0.58
Ratio of Capital to Annual Output	1.81	2.3	1.93	2.18	2.23
Ratio of Investment to Output	0.25	0.3	0.19	0.22	0.22
Ratio of Government Spending to Output	—	—	—	—	0.20
Risk-Free Rate, Annual	3.0%	3.4%	6.2%	4.0%	4.0%
Net Interest Margin, Annual	2.0%	3.6%	2.3%	1.1%	1.6%

Note: The net interest margin is defined as net interest income divided by interest-earning assets.

In the general equilibrium approach common to all the models, the exogenous shortfall has drastically varied implications for bank net equity. Apart from additional model-specific mechanisms, bank net equity does not simply reflect the size of the exogenous transfer shock because the general equilibrium nature of the models imply important movements in asset prices, which feed back into the determination of the hit to bank net equity. At one end of the extreme, the multi-sector model of Guerrieri and Jahan-Parvar implies only a modest drop in bank net equity which mounts as the transfer shock builds in size. Demand from firms not reliant on bank credit keeps asset prices afloat.²⁷ At the other end of the spectrum, in the model by Covas and Driscoll, the anticipated drop in credit resulting from the mounting transfer shock leads to a sizable fall in bank equity since their non-linear modeling approach does not assume capital constraints that bind all the time. Accordingly, banks can lower their equilibrium capital ratios offset the effect of the capital shortfall shock.

Across all models, the drop in net equity leads to a contraction in the supply of credit and an increase in the spread between interest rates on lending and on deposits. Despite differences in magnitudes, the persistence of the movements is elevated across all models and reflects the persistence of the drop in net equity. In this respect, the model of Kiley and Sim is an outlier in our group. In that model, access to outside equity allows for a quicker recapitalization of the financial sector that reduces the persistence of the drop in net equity and of the change in spreads between lending and deposit rates. While firms in the model of Queralto also have access to outside equity that could potentially curb the persistence of the response of bank equity in a similar fashion, in that model outside equity is intertwined with the specification of the principal-agent problem at the core of the model in such a way that financial intermediaries prefer to avoid recapitalizing more quickly and rely more prominently on the accumulation of internal equity through retained earnings. Because

²⁷As shown above, even in the model of Guerrieri and Jahan-Parvar, an economy-wide shock would lead to large reductions in asset prices more closely comparable to those obtained in the other models presented.

these modeling differences ride through general equilibrium channels, a limited information approach to the estimation of the cost of issuance of outside equity would be ill suited to discriminating between these different results.

Notably, some of the differences in the response of net equity in the model by Covas and Driscoll are made more apparent by a different calibration approach that focuses on matching details of the commercial banking sector, rather than a stylized overall financial sector in the other models, and results in a magnification in the drop of bank capital in percent terms.

The disparities in the behavior of bank equity account to a large extent for the different spillover effects to the rest of the macroeconomy, as made apparent by the right column of figure 17. Focusing again on outliers, the drop in investment ranges between about 2 and 14 percent. A variety of modeling choices accounts for these disparities. The responses in the model of Guerrieri and Jahan-Parvar and in the model of Covas and Driscoll are compressed due to the interaction among sectors—the sector-specific transfer shock is compensated by increased lending from complementary sources. Such mechanism, by contrast, is muted in Iacoviello's model and Kiley and Sim's model. In Iacoviello's model, even if 50 percent of capital is produced by unconstrained firms, the complementarities across constrained and unconstrained firms are such that unconstrained firms cannot undo the drop in labor and capital demand that follow a credit crunch. Similar mechanisms also apply to Kiley and Sim's model.

The consumption side reflects an even broader range of outcomes. In some models, the baseline financial shock *boosts* aggregate consumption—the transfer shock considered is a windfall for the household sector. In other models, such as that of Covas and Driscoll and that of Iacoviello, the windfall is offset by the fact that the banking sector cuts dividends sharply in order to boost the recapitalization process by retaining earnings. The models of Queralto and of Guerrieri and Jahan-Parvar do not embed this mechanism, as dividends are not explicitly modeled.

Finally, all models predict a contraction in output, but the magnitudes differ greatly, ranging from a 5 percent contraction of the

model of Iacoviello to a contraction below 0.5 percent in the model by Guerrieri and Jahan-Parvar. Apart from the interaction across sectors, sensitivity analysis to parametric assumptions brings out the importance of the interaction between financial frictions and the labor market to gauge the effects on aggregate output. With capital predetermined in all models and with the transfer shock not able to affect real assets on impact, the immediate fall in output has to ride through a contraction in hours worked. In this respect, apart from extant differences in modeling approaches, different calibration choices regarding the Frisch elasticity of labor supply across the models play an important role in determining disparities in results.

8.1 Harmonized Calibration

Table 6 summarizes key parameters across models, including the Frisch elasticity of labor supply. To gauge the importance of differences related to alternative calibration choices, we also considered a harmonized calibration, reported in the last column of the table. As some of the parameters govern features not included across all of the models considered, for ease of comparison, where necessary, we shut down some of the missing features, as in the case of adjustment costs for loans or deposits, or for consumption habits. For the other parameters we settled on representative estimates from the literature.

Figure 18 compares the effects of the baseline transfer shock across models under the harmonized calibration of table 6.²⁸ The harmonization of the parameter values slightly compresses the range of model responses, but, even with a common calibration, there remain substantial differences across models. In sum, the figure reinforces the headline finding of our analysis that economic modeling choices (more so than different parameter choices) can dramatically affect the results across models to the same size shock.

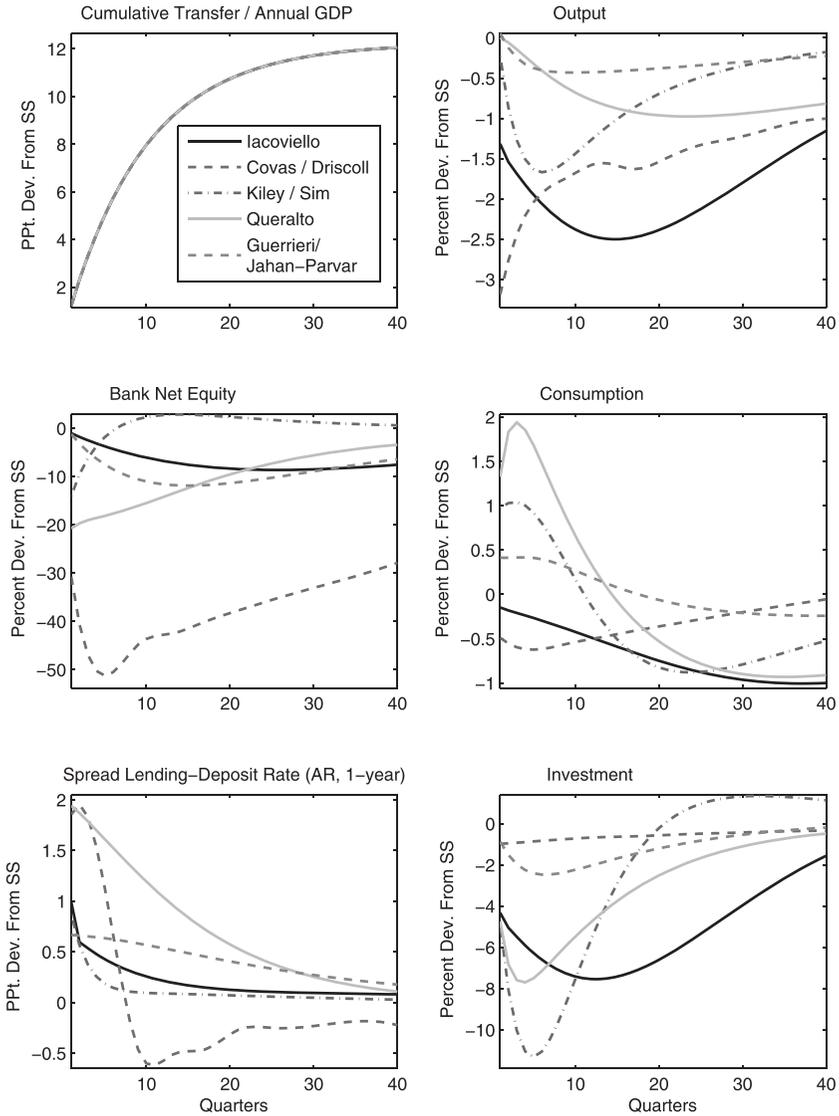
²⁸Parameters not included in table 6 are unchanged relative to the calibration tables in the online appendix.

Table 6. Harmonized Calibration

Parameter	Iacoviello	Covas/ Driscoll	Kiley/Sim	Queralto	Guerrieri/ Jahan-Parvar	Harmonized Value
Capital Share	0.35	0.36	0.4	0.33	0.33	0.33
Capital Depreciation Rate	0.035	0.021	0.025	0.025	0.025	0.025
Average Discount Factor	0.975	0.988	0.985	0.99	0.99	0.99
Are There Adjustment Costs for Loans or Deposits?	Yes	Yes	No	No	No	No
Consumption Habits	0.46	0	0.37	0.75	0.82	0
Risk Aversion for Households	1	2	1.57	2	1	1
Frisch Labor Supply Elasticity	2	0	1.05	3	1	1

Note: Columns 2–6 report the parameters used in each model. Column 7 reports the parameters chosen for a harmonized calibration.

Figure 18. Horizontal Model Comparison with Harmonized Calibration



Notes: The figure shows responses to the baseline transfer shock (whose calibration is described in section 2) across all the models of the sections from 3 to 7 using the harmonized calibration described in section 8. For ease of comparison, the responses for the yearly model of Covas and Driscoll were interpolated to quarterly frequency using splines.

8.2 VAR Estimates

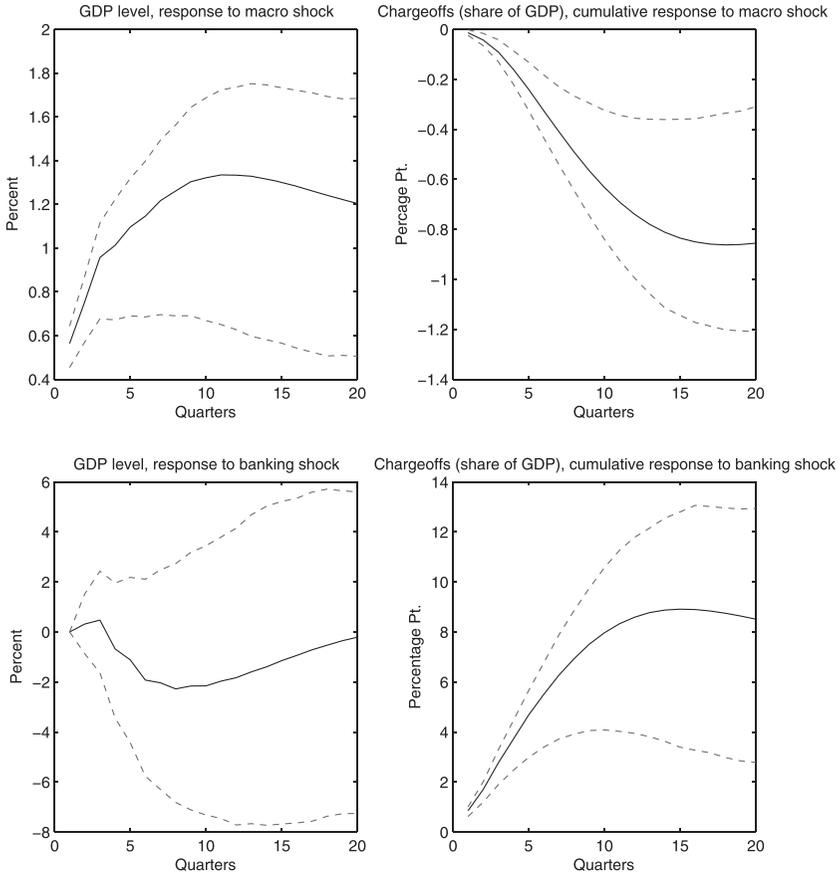
In order to check if any of the models presented are outliers relative to simple empirical evidence, we considered a variety of vector autoregressions. Capital shortfalls can stem from sources ranging from changes in the valuation of available-for-sale assets on the portfolio of banks to reductions in income. The simple empirical evidence presented below focuses on increases in charge-offs on loans and leases.

We run a bivariate VAR of U.S. real GDP growth and charge-off rates on loans and leases for the period 1985:Q1–2016:Q3 using four lags.²⁹ Using a simple recursive identification scheme, we identify two shocks: a macro shock, an innovation to GDP that contemporaneously affects loan charge-offs; and a loan charge-off shock (a banking shock), which does not affect GDP contemporaneously. We then rescale the loan charge-off shock so that, when expressed as a fraction of GDP, total loan charge-offs rise after nine quarters so as to imply a shortfall sized at 7.5 percent of GDP, just like in our model comparison exercise. The VAR results are shown in figure 19. The shock to loan charge-offs, shown in the bottom row, produces a mean contraction for GDP in the neighborhood of 3 percent after two years. The shaded areas in the figure represent 90 percent bootstrap confidence intervals.

Figure 20 overlays the 90 percent confidence interval for the GDP response from the VAR with the model responses under the original calibrations (top panel of the figure) and under the harmonized calibrations (bottom panel of the figure). From this comparison we conclude that the range of outcomes consistent with sampling uncertainty from the empirical VAR is similar to the range of outcomes from our models. Moreover, this range of uncertainty is also consistent with the outcomes from simple empirical frameworks presented, for instance, in BCBS (2010).

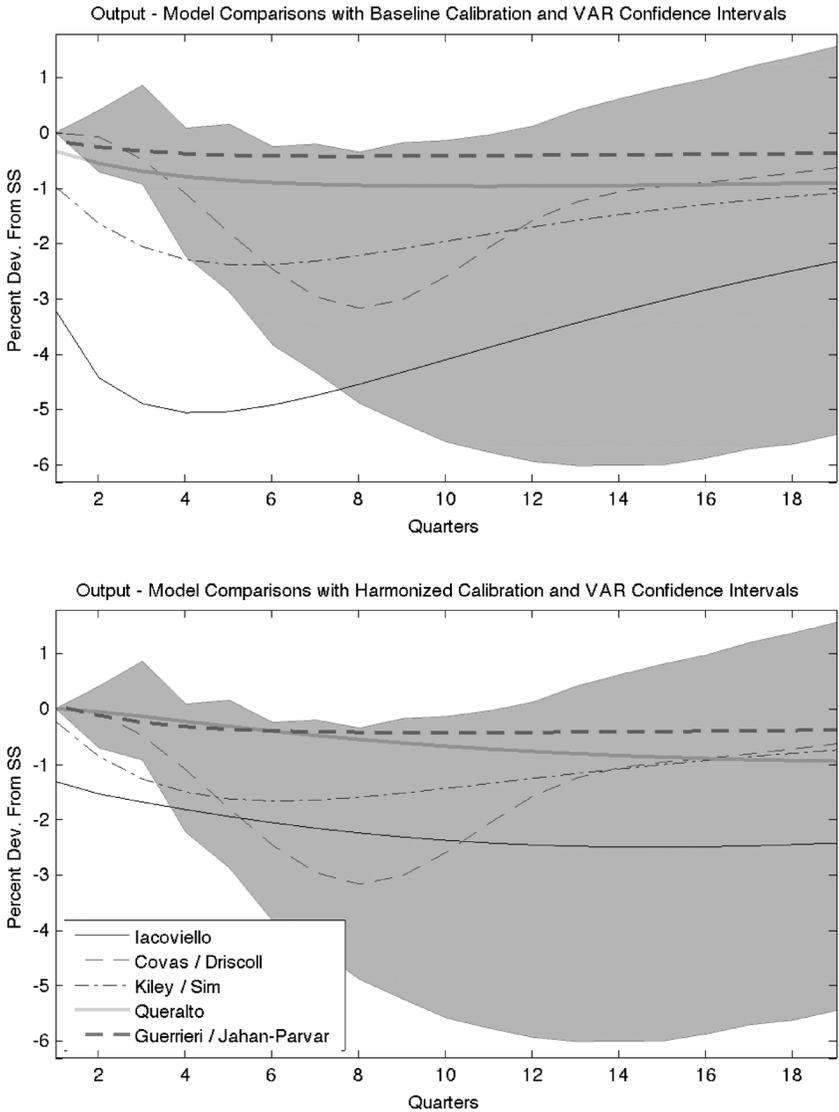
²⁹Charge-offs are expressed as a share of GDP by multiplying loan charge-off rates at all insured commercial banks (Haver mnemonic: DY@USECON) by loans and leases in bank credit (FABWA@USECON) and dividing by nominal GDP (GDP@USECON).

Figure 19. Responses Estimated Using a VAR



Notes: The solid lines show point estimates for the response to recursively identified shocks from a bivariate VAR of order 4, which includes GDP growth and charge-off rates for all commercial banks. The dashed lines denote 90 percent bootstrap confidence intervals.

Figure 20. Comparing Model Uncertainty and VAR Sampling Uncertainty



Notes: The shaded area represents a 90 percent bootstrap confidence interval for the response of U.S. GDP to a banking shock identified from a VAR. The top panel compares this measure of VAR sampling uncertainty with the output responses from the models under the original calibrations. The bottom panel shows analogous model responses under a harmonized calibration. See table 5 for the calibration details.

9. Conclusions

Despite a common core, models that emphasize a complementary set of linkages between the financial and the real sectors produce a wide array of predictions for the macroeconomic effects of a shortfall in capital. All the models presented imply that the baseline shock that produces a capital shortfall similar in size to that gauged under the U.S. stress-test program would lead to a contraction in output. However, the size of this contraction varies greatly across models.

We draw the following conclusions:

- General equilibrium channels can exert a large influence on the spillover effects of capital shortfalls through the response of asset prices such as the price of capital and interest rate spreads.
- The interaction between alternative sectors that can provide financing is an important determinant of the availability of credit and of the size of the macroeconomic consequences of shortfalls in capital. In turn, important implications of this interaction ride through asset prices.
- The modeling of alternative sources of financing can lead to large differences in results. The interaction among alternative financing sources can generate subtle differences across models. For instance, recapitalization associated with outside equity can be influenced by readily measurable costs, such as costs of issuance, as well as by more subtle structural features of the economy, such as the effect of outside equity on incentives of banks.
- If the financial shock does not imply the destruction of physical resources, as for our baseline transfer shock, the macroeconomic spillover has to work through a contraction in hours worked on impact. Accordingly, refinements of the linkages between financial frictions and frictions in the labor market would bolster our understanding of the macro effects of financial shocks.
- Finally, sensitivity analysis shows that the sources of shocks to financial positions can have a large influence on their macroeconomic effects.

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