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Financial Crises in DSGE Models: Selected Applications of MAPMOD

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Abstract

This paper, together with a technical companion paper, presents MAPMOD, a new IMF model designed to study vulnerabilities associated with excessive credit expansions, and to support macroprudential policy analysis. In MAPMOD, bank loans create purchasing power that facilitates adjustments in the real economy. But excessively large and risky loans can impair balance sheets and sow the seeds of a financial crisis. Banks respond to losses through higher spreads and rapid credit cutbacks, with adverse effects for the real economy. These features allow the model to capture the basic facts of both the pre-crisis and crisis phases of financial cycles.

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I. Introduction

This paper, together with a companion paper (Benes, Kumhof, and Laxton, 2014), presents MAPMOD, a new model that has been developed at the IMF to support macrofinancial and macroprudential policy analysis. While the technical companion paper discusses the theoretical structure of MAPMOD, this paper presents its simulation properties. MAPMOD has been designed specifically to study vulnerabilities associated with excessive credit expansions and asset price bubbles, and the consequences of different macroprudential policies that attempt to guard against or cope with such vulnerabilities.

As has been emphasized in a number of recent theoretical and empirical studies by the world's leading policy institutions (see for example Macroeconomic Assessment Group, 2010), the critical macroprudential policy tradeoff is between reducing the risks of very costly financial crises and minimizing the costs of macroprudential policies during normal times. It is therefore crucial to design analytical frameworks that clearly articulate the role of the financial sector and of macroprudential policies. We argue that such new analytical frameworks require a major revamp of the conventional linear dynamic stochastic general equilibrium (DSGE) models that, in the period before the financial crisis of 2007/8, had been designed for conventional monetary policy analysis (Borio, 2012). Some progress has been made, but much work remains to be done. In our view, an area that requires particular attention is the special role played by banks, most importantly the role of bank balance sheets.[1] This includes, as we will discuss in much more detail in the next section, the role of bank equity in absorbing lending losses, the role of bank loans in creating new purchasing power to finance consumption and investment (both real and financial), and the role of bank deposits as the economy's principal medium of exchange, with all of these subject to balance sheet risks that generate highly nonlinear feedback between bank balance sheets, borrower balance sheets and the real economy during financial crises.

MAPMOD does feature banks and bank balance sheets that play these fundamental roles, and the globally nonlinear version of the model allows to capture the basic stylized facts of both the pre-crisis and crisis phases of financial cycles. Claessens, Ayhan, and Terrones (2011) and Borio (2012) suggest that the financial cycle can be described parsimoniously in terms of credit and property prices, with rapid growth in these variables providing an

[1] Many of the recent DSGE models with financial frictions abstract from bank balance sheets altogether by modeling all lending as direct, others (the majority) feature trivial bank balance sheets that require no net worth because all lending risk is diversifiable, and the remaining small group of models that does feature bank equity models banks not as lenders subject to lending risk, but as investors subject to price risk.

important early warning indicator of potential future financial crises, and with very painful recessions and slow recoveries being associated with large contractions in credit and house price busts. However, Claessens, Ayhan, and Terrones (2011) also find that not all credit expansions are followed by financial crises. Furthermore, it can be very difficult to distinguish fundamentally sound ("good") and excessive ("bad") credit expansions and asset price bubbles in real time. MAPMOD is designed to study the critical differences between good and bad credit expansions. Moreover, it also allow us to study alternative macroprudential policies, including not only their role in dealing with the immediate aftermath of a crisis, but also their role in preventing a crisis from occurring in the first place, for example by making it unattractive for banks to let credit grow too fast or too far.

The remainder of this paper is organized as follows. Section II provides an overview of our modeling philosophy and the key design features of MAPMOD. Section III presents three simulations that are designed to highlight the fundamental interactions between banks and the real economy, including examples of good and bad credit expansions driven by shocks to productivity, borrower riskiness and asset prices. Section IV shows three further simulations that are used to illustrate the implications of nonlinearities under conditions of excessive leverage in the banking and non-financial sectors, as well as the potential role of countercyclical macroprudential policies in limiting the effects of such nonlinearities. Section V shows three final simulations that illustrate the versatility of the model in encompassing a wide variety of other financial stress scenarios, including shocks to bank equity, to minimum capital adequacy ratios, and to foreign interest rates. Section VI provides some concluding remarks. Furthermore, in Appendix A, we report and briefly discuss the baseline calibration used in the simulations. Appendix B describes the exact numerical assumptions underlying the individual simulation experiments. Appendix C provides a complete set of figures with simulation results.

II. Modeling Philosophy and Key Design Features of MAPMOD

During financial crises we observe major deviations in the behavior of agents and in macroeconomic variables from what prevails during normal times. Specifically, the economic mechanisms become inherently nonlinear when subjected to large distress events, a point emphasized by many authors, such as Milne (2009), and furthermore there can be vicious interactions between asset prices, bank lending conditions and the real economy that magnify such effects (Borio, 2012). Bank balance sheets play a critical role in such interactions. Conventional linearized DSGE models are not very useful for evaluating macroprudential policy tradeoffs under such conditions, first because by construction they do not capture the effects of nonlinearities, and second because they ignore the special role played by banks in contributing to vulnerabilities and nonlinearities. Banks, especially if left unregulated, can fundamentally change the economic propagation mechanism, through their response to standard demand and supply shocks that emanate from outside the banking system. But in addition, banks can themselves become an important source of shocks, for example by setting lending terms that reflect overly optimistic expectations concerning growth prospects, borrower riskiness or asset prices.

Given the existence of fundamental uncertainty about the nature and persistence of the underlying shocks, and therefore about the sustainability of existing lending practices, models can provide an important framework for assessing alternative policies, and ensuring that these policies are reasonably robust to such uncertainty, and based on the existing state of knowledge. This paper presents a prototype model that has been specifically designed to support macrofinancial and macroprudential policy analysis. As such, it assigns a central role to banks, and it incorporates important endogenous and nonlinear feedback mechanisms between bank balance sheets, borrower balance sheets and the real economy. The role of banks in this model differs in several fundamental ways from the way in which banks are conceived in existing DSGE models. Below we provide a partial list of these differences.

First, banks maintain a stock of net worth that enables them to absorb loan losses. They do so for a number of reasons: because of Basel-style minimum capital adequacy regulation, because acquiring additional net worth directly from the equity markets is subject to frictions, and because bank lending is subject not only to diversifiable borrower-specific idiosyncratic risk, but also to non-diversifiable aggregate risk that makes lending inherently and endogenously risky.

Second, banks' determination of the price and quantity of loans, and their maintenance of capital buffers above minimum requirements, arise as an optimal equilibrium phenomenon resulting from the interactions between loan contracts, endogenous loan losses and regulation.

Third, in the process of making new loans, commercial banks create matching liabilities (bank deposits) for their borrowers, thereby expanding their balance sheets. In so doing, banks are limited only by their perceptions of profitability and by the risk absorption capacity of their capital.[2] The main implication of the credit creation process is that bank loans give borrowers new purchasing power that *did not previously exist*. This is highly beneficial during periods of strong economic fundamentals, when it is essential that banks provide the purchasing power that the economy needs to allow consumption, investment and real wages to grow in line with the economy's potential. Macroprudential policies that attempt to prevent a credit expansion under such circumstances can therefore be costly. But the very same flexibility can at times result in an excessively large and risky loan book, especially when risk becomes underpriced. As emphasized by Borio (2013), this can make the balance sheets of both banks and their borrowers very vulnerable to shocks, thereby sowing the seeds of a financial crisis that may happen many years later.

Fourth, banks respond to financial shocks, and the resulting balance sheet dislocations, through a combination of higher spreads and non-price credit rationing. With bank credit rapidly shrinking during financial distress, households and firms are cut off from one of their principal sources of financing exactly when they need it the most.

Fifth, during severe financial crises vicious and highly nonlinear feedback effects between borrower balance sheets, banks balance sheets, and the real economy characterize the economy.

There are two such nonlinear feedback effects. First, lending losses can lead to a serious erosion in banks' capital adequacy taking them close to, or even below, their regulatory capital minimum, where penalties start to apply. This triggers a very rapid contraction in lending to immediately move banks out of that danger zone. It is accompanied by higher lending spreads, as banks attempt to replenish their equity buffers so as to move more durably away from that danger zone, on the basis of higher equity rather than reduced lending. But, second, lending losses are also a reflection of the fact that the balance sheets of banks' borrowers have become far more vulnerable, due to declines in the value of their assets, with the resulting steep increases in loan-to-value ratios providing another reason for reduced lending volumes and higher lending spreads. The resulting nonlinear responses of lending volumes and lending spreads act as a strong amplifying mechanism that further exacerbates the balance sheet problems of bank borrowers, and therefore of banks themselves. The adjustment to such shocks can therefore be very protracted, and very costly. Due to the nature of their operations and regulatory environment, banks impose tighter financial conditions precisely at the time when the real economy would ben-

[2] Unlike in the loanable funds model, the decisions by bankers to make loans are not constrained by an available supply of pre-existing saving, or by central bank reserves, but rather by expectations of return and risk, and their interactions with prudential regulation insofar as it affects the return and risk of lending.

efit from more countercyclical lending (Borio (2012)). This then of course directly leads to an important policy implication, namely the need for macroprudential policy to encourage banks to adopt a more countercyclical stance.[3]

We emphasize that the painful contractions that accompany financial cycles in MAPMOD, and in the real world, are not only a reflection of deteriorating fundamentals themselves, such as large downward revisions of expected future economic growth rates, as would be the case in conventional monetary business cycle models. Nor are they only a function of deteriorating bank-specific fundamentals, such as reductions in bank borrowers' creditworthiness, although this does of course play an important role. Rather, the severity of financial crises stems to a very large extent from the fact that, following downward shocks to economic fundamentals, banks endogenously become more vulnerable. The reason is that the leverage of banks and their borrowers, which will have grown in response to previous exaggerated expectations concerning future growth and future lending risk, can quickly expose banks to nonlinear contractionary effects when expectations are revised downwards and when, consequently, lending losses occur.

In modern financial systems banks are not constrained on the margin by a pre-existing level of deposits, but have the ability to expand both sides of their balance sheets simultaneously, by making loans and generating demand deposits. This means that their lending, and provision of purchasing power to the economy, can expand and shrink at a much faster rate than traditional models would suggest. But, given uncertainty about the underlying creditworthiness of borrowers, this flexibility can be a double-edged sword. If banks correctly anticipate stronger fundamentals, the decision to make loans and generate purchasing power can result in a good credit expansion that helps to facilitate adjustment in the real economy. However, if these decisions are not in line with fundamentals, they can create vulnerabilities and a potential financial cycle, with an associated real contraction that can be very severe. Demonstrating this will be the primary objective of the following section of this paper.

III. Examples of Good and Bad Credit Expansions

We are now ready to present scenarios that illustrate the key mechanisms by which banks interact with the real economy. Each scenario consists of a set of charts divided into four

[3] Boissay, Collard and Smets (2013) have emphasized the important role of nonlinearities and liquidity in generating financial cycles in a DSGE model.

columns. The first column of charts shows GDP and the components of aggregate demand, namely consumption, investment and the trade balance (the latter relative to GDP). The second column shows key price variables, namely wage and CPI inflation, the policy interest rate, and the real exchange rate. The third column shows the main nonbank financial variables, including net foreign assets (relative to GDP), the physical capital stock,[4] real asset prices (the value of a unit of the physical capital stock), and finally the product of the preceding two variables, the real value of the capital stock, which represents the real value of collateral for bank lending. The fourth column shows bank-specific financial variables, starting with the level of real bank credit, followed by the pre-default or ex-ante lending spread, the loan default rate and the post-default Basel capital adequacy ratio. A blue box encloses the five key banking system variables.

To illustrate the potential implications of excessive credit expansions, our discussion initially will deliberately exclude a countercyclical macroprudential policy response, the absence of which makes the economy more vulnerable to revisions in beliefs.[5]

A. Revisions in Views About Trend Productivity Growth

Figure 1 shows the first of our model simulations. It consists of two scenarios that illustrate the differences between good and bad credit expansions, meaning credit expansions that are based on correct versus overly optimistic expectations about fundamentals.[6] We emphasize that these simulations are not calibrated to any particular country or region, but are designed simply to illustrate MAPMOD's key mechanisms. Future work will apply this framework to individual economies.

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[4]Physical capital is an input into production in our model. It can be however thought of as a proxy for a combination of other real assets, including housing. The model does not take a stand on whether the shocks and imbalances are specific one particular sector.

[5]Given that any forecast has a zero probability of being realized, it is not difficult to motivate the seeds of a crisis being sown partly by *mistaken beliefs*. However, in circumstances where banks have incentives to underestimate uncertainty and take on excessive risk, it might be more appropriate to refer to them as *mistaken assumptions*. The model does not deal with issues related to why banks engage in excessive risk-taking, but has been designed as a simple analytical framework to study the macroeconomic implications thereof, and of macroprudential policies designed to deal with such behavior.

[6]Several recent papers using DSGE models have emphasized the important role of perceptions about fundamentals (changing views about future productivity or the riskiness of borrowers) to explain historical business cycle fluctuations. See Juillard and others (2008), Jaimovich and Rebelo (2009), Christiano and others (2010), and Blanchard, L'Huillier, and Lorenzoni (2013). However, these models abstract from important vulnerabilities that are associated with excessive expansions of bank balance sheets.

Figure 1 assumes that all agents initially expect higher trend productivity growth rates in the economy's export sector over the subsequent 10 years, with the result that the economy's level of potential (and actual) output in the long run is expected to rise by approximately 10 percent;[7] the exact numerical assumptions used in this simulation are summarized in Table 3. Anticipation of this effect leads to an initial surge in both consumption and investment ahead of the more gradual increases in potential output as the capital stock adjusts slowly. Over the first three years, the two scenarios are identical, because in both of them realized growth rates coincide with previously expected growth rates over that period. But starting at the beginning of the fourth year, the two scenarios begin to diverge. The black solid lines, which represent the good credit expansion, assume that expectations of higher future productivity growth continue to be correct, so that output does eventually grow by 10 percent. By contrast, the red dashed lines, which represent the bad credit expansion, assume that realizations and expectations of higher aggregate productivity *growth* are revised back to baseline rates at the beginning of the fourth year, so that less than a third of the initially expected increase in the *level* of potential output in the long term is in fact realized.

In these scenarios, banks play a fundamental role in accommodating the increase in aggregate demand and supply that results from expectations of improved fundamentals, but at the same time their balance sheets become increasingly vulnerable should those expectations turn out to be overly optimistic. The flexibility of the private financial system is therefore a double-edged sword, with sizeable benefits during good credit expansions but larger costs during the downturn phase of bad credit expansions. Under a good credit expansion private banks flexibly provide the additional purchasing power to finance new expenditures demanded by a growing economy,. This greatly facilitates the economy's adjustment to better growth prospects. For example, increases in purchasing power of both consumers and firms allow real wages and thus incomes to increase through an increase in nominal wages, rather than through a decrease in goods prices that would otherwise slow down the supply response to higher productivity. Under a bad credit expansion, the economy benefits in exactly the same way over the initial boom period. But it also builds a number of balance sheet vulnerabilities that can go unnoticed while the economy expands, and that unleash large and nonlinear contractionary effects in case the optimism that drives the initial credit boom is exposed as excessive.

[7] Expectations are assumed to improve in a gradual and linear fashion over the first four quarters shown in the simulation. Consequently, agents only begin to expect the full 10 percent long-term improvement in potential output by the fourth quarter. While it is important to emphasize that these simulations are illustrative they roughly mimic the significant upward revisions in potential growth that were observed in many countries before the global financial crisis.

In the scenarios of Figure 1 banks significantly affect the propagation mechanism of shocks, but the source of shocks is outside the banking system. We will later contrast this with scenarios where banks themselves are the source of shocks, through a change in banks' expectations about fundamentals that differs from those of non-bank agents.

We begin our detailed discussion of the simulation experiment by commenting on the good credit expansion scenario represented by the solid black lines. Due to the gradual nature of the shock, the supply-side effects of higher productivity growth take time to arrive, while the demand-side effects on consumption and investment, which are due to immediate improvements in expected future income and profits, happen much more quickly. Investment increases particularly fast, and by year three ends up almost 12 percent above its initial level. Due to buoyant demand, GDP initially rises ahead of increasing potential, but over the longer run rises in line with potential, by ultimately 10 percent. Ceteris paribus these initial demand pressures would cause inflationary pressures, but over the first two years these are almost exactly offset by cost reductions from exchange rate appreciation. The disinflationary effects of ongoing further productivity growth dominates from the third year onwards, with headline inflation eventually falling by around 1.2 percentage points in year 5. As a consequence, the policy rate stays essentially constant over the first two years, and then drops in line with the forecast of lower headline inflation. Demand pressures also lead to a strong and highly persistent real appreciation,[8] accompanied by a very persistent deterioration in the trade balance that reaches almost 2 percent of GDP in the second year. As a result, the net foreign asset position deteriorates by about 3.5 percent of GDP at the end of the third year, and by almost 4.5 percent of GDP after five years. As the economy's exports benefit from the improvements in productivity, the trade balance and the net foreign assets position eventually improve, but the latter takes many years to unwind. We can see here the first balance sheet vulnerability developed in the economy as a result of more optimistic expectations, namely its greater exposure to a reversal in conditions in international capital markets. This will not be explored in this section, but will be taken up in one of the later simulations reported in Section V.

Banks accommodate the surge in demand that follows better growth prospects, both through very fast growth in the volume of lending and thus of purchasing power, and through a lowering of spreads. But it is the quantity aspect that dominates, both initially and over time. The reduction in spreads in the short run is small at less than 50 basis points, and in

[8]The behavior of the nominal exchange rate is very similar to that of the real exchange rate.

fact spreads start to increase relative to their initial value from the middle of year three.[9] A related development can be observed in bank capital adequacy ratios, which start at 11.4 percent, meaning at a buffer of 3.4 percent above the minimum capital adequacy ratio of 8 percent. Once banks start to perceive improved prospects for their borrowers, they are willing to live with a reduced buffer of 3.1 percent. This lower capital buffer is the result of banks increasing the spread on their loans slowly (after the initial decline) while the volume of loans increases very fast.

Improved economic prospects, accommodated by increased provision of loans and purchasing power by banks, lead to both an increase in the stock of capital and an increase in real asset prices. This of course means that the value of collateral increases over time, which in turn supports the increase in bank lending and the drop in spreads. As a result the stock of real bank credit increases by almost 8 percent after three years, and by well over 20 percent in the long run. This of course is the second, and generally much more important, balance sheet vulnerability developed by the economy as a result of more optimistic expectations, namely its greater exposure to a reversal in conditions in domestic banking markets. This includes both the vulnerability of borrower balance sheets, through potentially excessive capital accumulation and unsustainable real asset prices, and the vulnerability of bank balance sheets, through potentially excessive accumulations of loans that might not be repaid in full.

This takes us to the bad credit expansion scenario represented by the red dashed lines in Figure 1. Here there is a sudden reversal in expectations, and in realizations, of further productivity growth from the end of the third year. This reversal causes an immediate and steep drop in real asset prices of over 6 percent, and a real output contraction of around 4 percent. Qualitatively similar effects would be observed even in a conventional monetary business cycle model, but the effects are much stronger in the presence of banks. The reason is that banks need to respond immediately to two adverse events, a reduction in the value of lending collateral and lending losses. Banks' response comes in two forms that both generate a vicious and nonlinear feedback loop to asset prices, a drop in lending and an increase in lending spreads. The reduction in the lending volume is highly persistent, while the increase in spreads is more temporary.

[9] Ceteris paribus, higher productivity growth would significantly increase the creditworthiness of all borrowers. However, banks' ability to instantly create a large volume of additional loans makes it possible for them to increase lending so fast that the riskiness of the marginal loan remains almost as high as before the shock. This helps to explain the small reduction in spreads following the shock.

The reasons for banks' behavior can be found in both the balance sheets of their borrowers and in their own balance sheets. Borrowers are suddenly perceived to be riskier than before, due to a collapse in the value of collateral. This leads to a reduced willingness of banks to make new loans. But even more importantly it leads to large losses on the existing loan book, as banks are unable to recover sufficient collateral on defaulting loans. The size of loan losses equals around 0.5 percent of the value of all loans.[10] Spreads immediately rise by more than one percentage point (accompanied by ever stronger non-price rationing), but this has a one-period lagged effect on profits, so that the impact effect of the shock is nevertheless a roughly 0.5 percentage point deterioration in the banking system's average capital adequacy ratio, to around 10.7 percent. Banks face this shock with an already reduced equity buffer, because their prior optimism had led them to reduce significantly that buffer over the preceding three years.[11]

The measures taken by banks at this time take two forms. The first, an instantaneous and discontinuous reduction in the volume of lending of around 3 percent, accomplishes the objective of limiting the short-run deterioration in the capital adequacy ratio at a reduced level of overall activity. The reduction in lending is therefore not only a response to the deterioration in the balance sheets of borrowers, but also is a response to the deterioration in banks' own balance sheet. The second measure taken by banks, a steep increase in lending spreads of around 120 basis points on impact, accomplishes a slightly different objective. While it contributes to limiting the short-run deterioration in the capital-adequacy ratio, it would take unrealistic (and suboptimal) increases in spreads to fully offset the effects of lending losses on impact. Rather, banks use higher spreads to gradually rebuild their equity buffers over time, but with much of the action front-loaded to move away from the danger zone near the regulatory minimum. Over time this rebuilds lost equity, and allows banks to increase lending again while still improving their capital-adequacy position.

The real repercussions of the reversal in expectations, and of banks' response to this, are dramatic. Investment and consumption collapses, and not only due to deteriorating growth prospects, but also due to a collapse of financing and an increase in the cost of financing. The resulting 4 percent collapse in output occurs over two to three quarters. The collapse in aggregate demand leads to a complete reversal in the trade balance, a real depreciation,

[10]Note that the portfolio default rate is annualized to facilitate comparisons with lending spreads. Portfolio defaults in percent of the value of the total loan book equal the annualized rate divided by a factor of four.

[11]The reduction in the average equity buffer is of course only part of the story, both in the real world and in the model, because heterogeneity among banks implies that some of them are now below their regulatory minimum and start having to pay regulatory penalties, while others are close to the minimum and have to start taking emergency measures to avoid future penalties.

and a temporary drop in the rate of inflation that is even larger than under the good credit expansion (where, unlike in the bad credit expansion, further improvements in productivity keep reducing the cost of production).

There is not much that conventional monetary policy can do to offset these feedback effects in the financial sector. A reduction in the policy rate, in our simulation of around 2.3 percentage points two years into the crisis, does of course help to offset some of the pain of higher spreads. But the ability to affect balance sheet dislocations is much more limited, they simply have to unwind and return to more sustainable levels that are justifiable by the new and worse economic fundamentals. But policy does have other options beyond conventional monetary policy, and these can smooth the adjustment process of balance sheets. This is because some of the reasons for the presence of nonlinearities in the financial sector have to do with regulation, so that more flexible regulation can make the adjustment process less nonlinear. The main example, which we will study in one of the later simulations, is capital adequacy regulations, which can be designed to encourage banks to respond to a crisis in a more countercyclical fashion.

B. Underpricing of Lending Risk by Banks ("NINJA Loans" Shock)

Figure 2 shows the second of our model simulations. Here the main role of banks is no longer merely that of propagators of shocks that originate elsewhere. Rather, banks themselves become the main source of shocks and vulnerabilities, because they base their lending decisions on expectations that are not supported by fundamentals. Risky loans to borrowers that have no income, no jobs and no assets ("NINJA" loans) is an extreme form of such an underpricing of lending risks, but is a useful term for illustrating the fundamental role that banks play in assessing risks on their loan books, and how incorrect assessments of these risks can create vulnerabilities in the banking system that can have important implications for the real economy.

Figure 2 consists of two scenarios ("NINJA1" and "NINJA2") that are identical until the end of the third year, and that begin to diverge thereafter. Both scenarios are, in the terminology of the previous subsection, bad credit expansions whereby misperceptions create vulnerabilities on bank balance sheets and a financial cycle. The specific misperception is a downward revision in banks' assessment of the riskiness of borrowers, specifically a gradual reduction in the perceived standard deviation of the overall individual risk factor (the reduction amounts to 5 percent by the end of the third year), while the actual standard deviation remains unchanged. The exact numerical assumptions are reported in Table 4. Because lending losses occur when bank borrowers experience exceptionally bad productivity realizations, a perceived lower probability of such extreme events translates to lower expected lending losses at any given interest rate, and thus to a willingness by banks to offer more lending at better terms.

The figure then compares two highly illustrative sets of assumptions concerning the period starting at the end of the third year. The black solid lines (“NINJA1”) assume that banks’ expectations of borrower riskiness permanently remain at their reduced level, which means that they permanently deviate from the economy’s true borrower risk, but without this misperception ever being exposed (over the horizon shown) by a major reversal. This scenario is obviously a very simple, hypothetical example to show the implications of banks underpricing the risk over a number of years. The dashed red lines (“NINJA2”) assume that banks’ expectations of borrower riskiness gradually return to the economy’s true borrower risk, with most of that adjustment taking place within about three years. This triggers a financial and real contraction.

We begin by commenting on the “NINJA1” scenario represented by the black solid lines. Because banks perceive a gradual, and eventually permanent, improvement in the creditworthiness of their borrowers, they are willing to offer more credit on better terms. This can be seen in real bank credit, which increases by around 1.5 percent by the end of the third year, in lending spreads, which drop by around 15 basis points over the same period, and in the capital-adequacy ratio, which is allowed to drop by almost 0.5 percentage points in the long run. Increased lending by banks leads to an increase in investment that reaches 2 percent by the end of the third year, accompanied by a roughly 0.5 percent increase in real asset prices. There is an almost equally large increase in consumption of over 1.5 percent over the same period, which is due to the wealth effects of increased economic activity, combined with the stimulative effects of additional purchasing power, which equally affects consumption and investment. Some of the increase in investment is permanent, while the consumption boom is mostly temporary. GDP increases by around 1 percent by the end of the third year. The initial increase in demand also leads to an increase in the inflation rate that reaches 0.6 percentage points by the end of the third year, accompanied by an increase in the policy rate. These inflationary pressures are of course temporary, but, given the persistence of the shock, quite persistent. Another consequence of higher aggregate demand is a 1.5 percent real appreciation, a prolonged trade balance deterioration that reaches a maximum of 0.7 percent of GDP, and a reduction in the net foreign asset position that reaches just under 4 percent of GDP. In the long run of the “NINJA1” scenario, spreads remain permanently lower by around 5 basis points, and the level of credit remains permanently higher by around 1.5 percent. This leads to a permanent increase in the levels of investment and the capital stock of around 0.5 percent, and thus also to a long-run gain in GDP. Therefore, as long as banks' misperception of borrower riskiness is not exposed, the economy gains due to their misperception. But this comes at the price of greater vulnerability to a sudden reversal, which could result in larger downturn in the bust phase of the financial cycle.

This is illustrated in the "NINJA2" scenario, represented by the red dashed lines. Here banks, over a short time period that starts at the end of the third year, start to realize that their assessments of borrower riskiness have been overly optimistic. The consequence is a very fast contraction of lending back to its original level, and an immediate 20 basis points increase in lending spreads, with average spreads in fact thereafter remaining around 5 basis points higher than initially, as banks rebuild the equity buffer that they had allowed to erode while their expectations were more optimistic. The sudden tightening in financial conditions leads to a roughly 2 percent drop in real asset prices, and to bank lending losses of around 0.1 percent of the value of the loan book. These lending losses occur despite the fact that borrower riskiness, meaning the standard deviation of firm-specific productivity, has not changed at all. What has changed is banks' risk perception alone. This perception cannot immediately lead to tighter lending terms, given that those terms are determined one period in advance. But it can lead to tighter future lending terms, which immediately reduce today's asset prices and therefore the value of collateral. This in turn endogenously makes borrowers more likely to default, and lowers the fraction of loans that banks can recover in a default.

There are real repercussions of the reversal in expectations, and of banks' response to this. Investment and consumption drop, due to both the sudden reduction in credit supply and the increase in its cost. GDP drops by 1.75 percent. The real exchange rate depreciates and the trade balance improves. Inflation falls far faster than in the "NINJA1" scenario, as the sudden drop in demand adds to the disinflationary pressure of the policy rate.

We emphasize again that the source of the boom-bust credit and real cycle in this experiment is not a shock to non-bank fundamentals, but rather a change in banks' own behavior, specifically a change in their expectations that is not shared by the rest of the economy.

C. Excessive Credit Expansion Caused by an Asset Price Bubble

Figure 3 shows yet another example of a bad credit expansion, namely an increase in bank lending and creation of purchasing power that is fueled by a deviation of asset prices from their fundamental value, a phenomenon that is typically referred to as an asset price bubble. In this simulation, over the first three years, the expected future returns on physical capital used in domestic production equal their true fundamental values plus exogenous shocks that are not based on fundamentals. These shocks keep increasing period after period until they reach their maximum at the end of year three. Even in a model without banks, improved expectations about future returns lead to an increase in current asset prices. But in a model with banks, because asset prices are also a key input into banks' lending decisions, they trigger lending responses that make the eventual bursting of this bubble much more painful. Specifically, the asset price bubble leads to a perceived increase in wealth that triggers a demand-driven boom, and banks accommodate this boom by dramatically increasing the size of their balance sheet in order to create the purchasing power that is needed to support an increased volume of transactions. But this creates balance sheet vulnerabilities that make the ultimate crash far more severe. The crash is triggered by a sudden discontinuation of the non-fundamental shocks to expected returns, and therefore a precipitous drop in asset prices and the value of the collateral base.

For the particular sequence of shocks simulated in Figure 3, real asset prices increase by around 18 percent over the first three years. Note in Table 5 that the actual extent of the bubble is 10% at the end of the third year, while the rest of the observed real asset price increases is due to the economy's endogenous feedback. These developments make bank borrowers appear to be more creditworthy, and banks respond with a combination of increased lending and lower spreads. However, as in Figure 1, the increase in lending, at 9 percent after three years, is large relative to the reduction in spreads, which fall by less than 50 basis points over the same time period. Banks also allow their equity buffer to decline, from 11.4 percent to 10.8 percent, in view of the perceived reduction in lending risk.

The increase in bank credit has as its counterpart a roughly equal increase in bank liabilities, as banks fund their additional lending by creating additional purchasing power. This purchasing power, together with the wealth effect of perceived higher returns to capital, fuels a very large demand-driven boom, with investment increasing by around 24 percent by the end of the third year, consumption by almost 3 percent, and GDP by over 5 percent. The real exchange rate appreciates, the trade balance deteriorates, and so do net foreign assets, by almost 3 percent of GDP by the end of the third year. The demand-driven nature of the boom is evident in the behavior of inflation, which increases by around 0.7 percentage points over the first three years, followed by an increase in the policy rate.

The crisis at the end of the third year is triggered by a massive collapse in asset prices of over 25 percent, with asset prices initially undershooting their long-run values by around 8 percent. This implies that banks are faced with large shortfalls when they attempt to realize the collateral on defaulting loans, which results in loan losses roughly equal to 1.5 percent of the total value of loans, and an average capital adequacy ratio that deteriorates from 10.8 percent to 9.5 percent. Equity buffers have therefore been severely eroded even for the average bank, while a much larger number of banks than usual is now in violation of minimum capital adequacy regulations. While in response to this banks immediately raise their spreads by around 150 basis points, their main response is a massive and instantaneous 8 percent contraction in lending accompanied by a simultaneous and roughly equal-sized destruction of purchasing power. In the short run, it is this contraction in lending, rather than the increase in spreads, which helps most to limit the deterioration of capital adequacy ratios in the banking sector. Lower lending is therefore not only a response to damaged borrower balance sheets, but also a response to damaged bank balance sheets. The increase in spreads subsequently helps to rebuild bank equity over time, not only to offset the losses of the collapse of the bubble, but also to restore the original 11.4 percent capital adequacy ratio, as lenders now understand that the higher original equity buffer was consistent with fundamentals, in other words with the actual higher-risk lending environment.

The collapse in asset prices signals that investors dramatically downgrade their expectations of future returns. The main response of the real economy is therefore a precipitous collapse in investment, of around 15 percent within less than a year, and of over 25 percent eventually. But this collapse is not only driven by changed expectations, it is also affected by the above-mentioned severe tightening in lending conditions and in the availability of liquidity. The latter affects the entire real economy, and this is the main reason why consumption also drops precipitously, by about 5 percent within less than one year. The drop in GDP also equals around 5 percent. The steep drop in demand leads to a real exchange rate depreciation, a complete reversal in the trade balance due to a rapid collapse in imports, and a beginning of the unwinding of the foreign debt incurred during the previous three years. The drop in demand also reduces the rate of CPI inflation, with the policy rate following suit. But interestingly, the rate of wage inflation surges by over 100 basis points in the wake of the collapse, as a widespread collapse in the return to capital due to previous overinvestment allows workers to capture a larger share of the economic pie.

IV. NONLINEARITIES, LEVERAGE, AND MACROPRUDENTIAL POLICY

A. Financial Sector Vulnerabilities and Financial Crises

The scenarios in Figure 4 assume that a combination of the productivity shocks of Figure 1 and the borrower riskiness shocks of Figure 2 hits the economy simultaneously. The black solid lines, which will again be referred to as the good credit expansion, assume that there is no reversal in actual or expected productivity, and in expected borrower riskiness, at the end of the third year. The red dashed lines, which will again be referred to as the bad credit expansion, make the same assumptions about reversals in actual or expected fundamentals as the respective simulations in Figures 1 and 2.

The figure accomplishes two objectives. First, it illustrates a plausible sequence of events that can trigger economic developments similar to the period before and after the outbreak of the global financial crisis. The optimism prior to that crisis, which gave rise to the balance sheet vulnerabilities that made it so severe, involved improving expectations both about real economic fundamentals, and about the fundamentals of the financial system, as in our simulations. And the crisis involved reversals in both of these expectations, as in our simulations. Second, Figure 4 allows us to quantify the size of the nonlinearities that arise out of balance sheet vulnerabilities. We do this by showing that the effects of the combined shocks during crises, but not during normal times, are far larger than the sum of the effects of the individual shocks, particularly for the financial variables, but also for the real economy.

Because the economic mechanisms at work have already been explored in the context of Figures 1 and 2, we will mostly focus on a comparison of magnitudes. A comparison of the first three years following the shocks to productivity growth and borrower riskiness shows that the effect of the combined shocks is roughly equal to the sum of the effects of individual shocks, with real bank credit growing by around 9 percent (7.5 percent and 1.5 percent in Figures 1 and 2), spreads roughly unchanged by the end of the third year (approximately +10 basis points and -10 basis points in Figures 1 and 2), and real asset prices roughly unchanged by that time. The evolution of the real economy is also comparable, with investment growing by 14 percent by the end of the third year (12 percent and 2 percent in Figures 1 and 2), consumption growing by 5.5 percent (4 percent and 1.5 percent in Figures 1 and 2), and GDP growing by 5 percent (4 percent and 1 percent in Figures 1 and 2). The reason for these similarities is that prior to the onset of the crisis, nonlinearities play a fairly small role in the simulations, as shocks remain fairly small. As a result, the financial system is not exposed to major stress.

This however changes dramatically upon the reversal of expectations (and of realizations, for the case of technology shocks) at the end of the third year. We start by observing that the 12 percent collapse in asset prices is far larger than the sum of the effects of individual shocks (6 percent and 2 percent in Figures 1 and 2). This puts far greater stresses on the balance sheets of banks and their borrowers. First, the much larger collapse in asset prices means that borrowers' loan-to-value ratios increase by far more. Because the relationship between lending risk and loan-to-value ratios is highly convex, this generates a disproportionate increase in lending risk. Second, the much larger lending losses following the collapse in collateral values, at 2 percent of the value of assets (0.5 percent and less than 0.1 percent in Figures 1 and 2), mean that banks' capital adequacy ratio declines by a far more perilous 1.5 percentage points (0.4 percentage points and 0.1 percentage points in Figures 1 and 2). Because the relationship between the willingness to lend and capital adequacy ratios is also highly convex, this generates a disproportionate deterioration in lending terms.

The main deterioration in lending terms is a far larger increase in lending spreads of over 300 basis points (110 basis points and 20 basis points in Figures 1 and 2). But real bank credit also drops more precipitously, by more than 5 percent (less than 3 percent and less than 1 percent in Figures 1 and 2). The effects on the real economy are therefore also magnified, with investment dropping by 15 percent over the first two quarters following the crisis (9 percent and 2 percent in Figures 1 and 2), consumption dropping by 8 percent over the same period (4 percent and 1.5 percent in Figures 1 and 2), and GDP dropping by 6 percent (3.5 percent and 1 percent).

Coming back to our first above-mentioned objective for simulating this scenario, we therefore observe that both the depth of the contraction at the beginning of the fourth year, and the manner and magnitude in which it is triggered and accompanied by financial sector tightening, is quite comparable to what was observed at the onset of the Great Recession in 2008 and 2009.

As to the second objective, the lesson is that if vulnerabilities to bank and borrower balance sheets are large enough, the effects of sufficiently large real and expectational shocks can become very nonlinear. In that case, limiting the magnitude of shocks, or limiting their balance sheet impact through appropriate policies, becomes an overriding concern, because the combined effect of different shocks on the economy is far larger than the sum of their individual effects. This raises two issues that will be explored in the next two subsections, the appropriateness (or otherwise) of using linearized simulations to study large shocks with a financial-sector dimension, and the possibility of using macroprudential policies to limit the balance sheet impacts, and therefore the nonlinear effects, of such shocks.

B. Nonlinear versus Linear Simulations

All scenarios up to this point have preserved the full nonlinear structure of the model economy, including most importantly, as we have seen in Figure 4, the nonlinear effects originating in household, corporate and bank balance sheet vulnerabilities. However, among academics, and also among model builders and users at leading policy institutions, it is far more common to use linearized versions of the underlying models to produce scenarios. Traditionally, especially for conventional monetary policy analysis in linear-quadratic frameworks, this has been found to be adequate, and of course it has the advantage of much greater ease of use. However, as we will now show, in the presence of significant financial sector nonlinearities this approach can produce very misleading results.

Figure 5 illustrates this by simulating an identical sequence of shocks, in an identical model, but in one case preserving the nonlinear structure of our model while in the other case using a linearized version of our model. Specifically, the black solid lines in Figure 5 are identical to the red dashed lines in Figure 4, which used nonlinear simulation techniques to study the effects of a combined shock to productivity growth and borrower riskiness expectations. We study the bad credit expansion scenario of that figure, because it is in financial crises that the defects of using linearization techniques are particularly pronounced. Figure 5 shows that the linearized simulation does not adequately capture the crisis dynamics, as the nonlinear simulation generates a much more severe downturn in financial variables, and consequently in real economic activity.

The nonlinear crisis dynamics of our model manifest most dramatically in household, corporate and bank balance sheets, namely in steep increases in household and corporate loan-to-value ratios and in steep declines in bank capital adequacy ratios. They consequently also manifest in large increases in lending spreads and large declines in lending volumes. It is therefore in these financial variables that we observe the largest differences between the nonlinear and linearized simulations. All of these variables are simultaneously determined and linked by feedback effects, but we start our discussion with asset prices, which drop by 12 percent in the nonlinear simulation compared to only 6 percent in the linearized simulation. As a result of this much larger drop in asset prices in the nonlinear simulation, household, corporate and bank balance sheets move much deeper into the danger zone, where high loan-to-value ratios due to dropping collateral values, and low capital adequacy ratios due to loan losses (which equal 2 percent of the value of loans in the nonlinear simulation compared to 0.25 percent of the value of loans in the linearized simulation) give rise to much tighter lending conditions. Tighter lending conditions in turn feed back to even lower asset prices, so that an important part of the reasons for the larger decline in asset prices in the nonlinear simulation is the feedback effects from lending conditions. Lending conditions consist of lending spreads and the availability of finance. Pre-default lending spreads increase by over 300 basis points in the nonlinear simulation, but only by around 80 basis points in the linearized simulation. Bank credit decreases by 5 percent on impact in the nonlinear simulation, compared to less than 3 percent in the linearized simulation.

The much more severe deterioration of financial variables in the nonlinear simulation is also reflected in the behavior of the real economy, both in the depth of the downturn and in its speed. GDP declines by 7 percent peak-to-trough within the first year following the crisis, compared to a little over 4 percent in the linearized simulation. But not only is the contraction much deeper, it also happens significantly faster, with the low point of consumption and investment reached at least two quarters earlier. This is because the increase in spreads is far more extreme, and the destruction of purchasing power is far larger and more immediate, than what can be captured in the linearized simulation.

The lesson learned from Figure 5 is therefore that if shocks are large enough to do serious damage to household, corporate and bank balance sheets, this has nonlinear effects not only in the financial sector itself but also in the real economy. Linearized simulations, which tends to study the effects of shocks in a local neighborhood where the balance sheets are not particularly vulnerable, cannot adequately capture these nonlinear effects. Linearization, which has been successfully used to study the effects of shocks, and of economic policies that deal with shocks, during normal times and for conventional monetary policies, is therefore not an adequate simulation tool during crisis times and for macroprudential policies. When analyzing policies that attempt to prevent or deal with crises, it is therefore imperative that nonlinear simulations be used. The analysis of such policies is what we turn to next.

C. Countercyclical Macroprudential Policy

Figure 6 turns to the question of how macroprudential policy can encourage a more countercyclical response to both expansionary and contractionary developments. The scenario represented by the black solid lines is again identical to the second scenario (the red dashed lines) in Figure 4, the bad credit expansion. This scenario (and all other scenarios up to this point) assumes a constant minimum capital adequacy ratio (MCAR) of 8 percent. In Figure 6 it is therefore labeled the constant MCAR scenario. The scenario represented by the red dashed lines in Figure 6, labeled countercyclical MCAR, makes exactly the same assumptions about shocks. But in this case, the MCAR imposed by the regulator is modeled as time-varying in an asymmetric and countercyclical fashion. Specifically, on the downside the MCAR is never allowed to drop below 8 percent, while on the upside it is raised in response to positive year-on-year loan growth; the exact numerical path for the MCAR is reported in Table 6. In other words, in this scenario, if banks decide to increase lending, they have to support this by accumulating an additional capital buffer. The specific macroprudential rule used for this simulation assumes some policy inertia, which ensures that banks can comply with the gradually increasing MCAR without having to increase spreads too suddenly.

The constant MCAR scenario has already been discussed as part of Figure 4. We therefore concentrate on the differences between that scenario and the countercyclical MCAR scenario. Over the initial boom phase, because lending increases, the countercyclical macroprudential policy rule mandates an increase in the MCAR, which is shown as the dash-dotted blue line in the bottom right panel of Figure 4. This forces banks to maintain or even slightly increase their capital adequacy ratio despite actual or perceived lower lending risk. Of course, as in the constant MCAR scenario, relative to the MCAR the actual capital adequacy ratio decreases; in other words, the equity buffer above the regulatory minimum decreases as perceptions of risk improve. But the actual capital adequacy ratio increases by around 0.2 percentage points by the end of the third year. Banks accumulate this higher capital buffer through earnings from their lending operations, with lending spreads, again despite the reduction in borrower riskiness, starting to increase relative to their initial value after around one year. The resulting difference in spreads between the two scenarios equals around 30 basis points by the end of the third year. Also, the speed at which lending grows is reduced significantly under countercyclical MCAR, so that both slower loan growth and faster equity growth contribute to maintaining a higher capital adequacy ratio. Due to banks' much tighter lending policy, the boom-phase increases in the physical capital stock and in real asset prices are only about half as large as in the constant MCAR scenario.

Developments in the real economy over the initial boom phase reflect this policy-induced difference in the behavior of banks. Most importantly, the boom in investment, the portion of demand most directly affected by bank lending in our model, is smaller by almost two thirds. But consumption growth is also smaller, reflecting slower creation of purchasing power by banks. GDP grows by little over 3 percent by the end of the third year, compared to 5 percent in the constant MCAR scenario. The real appreciation and the deterioration in the trade balance are also less pronounced than in that scenario. Price inflation, which under a constant MCAR rises during the initial boom phase, immediately starts to decline, and therefore so does the policy rate.[12]

More moderate growth in bank balance sheets and therefore in liquidity and aggregate demand clearly imposes a cost on the economy during the initial boom phase, and if this boom is in fact based on a correct assessment of economic fundamentals, this cost is real and substantial. If the boom is, on the other hand, based on an incorrect assessment of economic fundamentals, the economy realizes very large benefits in a crisis. These benefits, due to the nonlinearities and asymmetries present in the model, and in the real world, can be far larger than the costs during the boom phase. We can see this by comparing the two simulations after the end of the third year.

Under the countercyclical MCAR scenario, as can be seen in the bottom right panel of Figure 6, the MCAR is assumed to be immediately lowered very substantially following the revision in expectations, by a full 1.5 percentage points, to its minimum of 8 percent. This permits banks to take far less drastic measures in response to the downturn while continuing to comfortably satisfy macroprudential regulations. Banks still make lending losses, but these are very small, with their capital adequacy ratio only dropping by around 0.25 percentage points. The reason is that lending losses are themselves a function of the policies adopted by banks following the onset of the contraction, with a smaller (in fact approximately zero) increase in spreads and a smaller (less than 1 percent) contraction in lending directly feeding into smaller effects on future earnings of borrowers, and therefore a much smaller drop in asset prices of around 2 percent, compared to 12 percent under constant MCAR. A smaller drop in asset prices, as we have seen in all of the preceding simulations, is a key prerequisite for healthier household, corporate and bank balance sheets. A comfortable capital adequacy position obviously creates a virtuous cycle that is a direct

[12] Wage inflation still rises initially, reflecting the positive productivity shocks.

result of the countercyclical policy response, by permitting smaller increases in spreads and a smaller contraction in lending.

The benefits of this much more benign tightening in lending conditions and the smaller collapse in real asset prices can be clearly seen in the real economy. The impact drops in investment and consumption are only a small fraction of the drops observed under constant MCAR, and the overall amplitudes of fluctuations in investment and consumption are at around one third and one half. GDP contracts by around 2 percent from peak to trough, compared to around 7 percent under constant MCAR. The much smaller demand contraction is also reflected in the behavior of inflation, which under countercyclical MCAR is barely affected by the onset of the recession, so that the policy rate also does not exhibit a major reversal. This ability of macroprudential policy to permit a reduced volatility of policy interest rates was stressed in Benes and Kumhof (2011).

The trade-off illustrated by these simulations needs to be considered very carefully. There may well be situations where policymakers are quite sure that a lending boom is based on sound economic fundamentals, and on realistic expectations about those fundamentals. In this case, raising capital adequacy requirements would impose significant costs while the probability of realizing the benefits, which occur during downturns, would be low. But there are likely far more situations where policymakers are quite unsure about the risk of a future reversal, and in this case caution should rule. The reason is that the costs of getting it wrong are extremely large, so that even a modest probability of getting it wrong, or more fundamental uncertainty where policymakers do not even feel capable of determining such probabilities, argues for a countercyclical macroprudential approach. The costs of getting it wrong are so large for all the reasons that we have been stressing throughout this paper, namely the nonlinearities and asymmetries originating on the balance sheets of households, corporates and banks, which can make a recession extremely sudden, deep and painful.

V. Other Shocks in Domestic and International Financial Markets

In this section, we present three additional scenarios that can be studied using our model. The common theme across all of them is that the shocks originate in financial markets, either in the domestic banking market or in international capital markets.

A. Contractionary Shock to Bank Capital

In Figure 7, we study the effects of an exogenous 20 percent loss of regulatory bank equity, in a single period. We simulate two scenarios that differ in how difficult it is for banks to recapitalize themselves following this shock. In the first scenario, shown as the black solid line, banks can recapitalize only from retained earnings, in other words by charging higher loan interest rates. In the second scenario, shown as the red dashed line, they can also recapitalize by accessing equity markets, subject to costs and delays that are parameterized by $\zeta_E = 0.5$ in the terminology of the companion paper (Benes, Kumhof, and Laxton, 2014), with the first scenario corresponding to $\zeta_E = \infty$.

The shock immediately reduces the banking system's capital adequacy ratio by 2.4 percentage points, from 11.4 percent to 9.0 percent, while the MCAR is assumed to remain at 8 percent. Given that the economy features a continuum of banks with a continuum of asset returns, these losses suddenly cause a much larger fraction of banks to violate the MCAR, with all remaining banks in much greater danger of violating it in the future. To avoid penalties, banks therefore adopt a two-pronged strategy if they can only recapitalize through retained earnings, and a three-pronged strategy if they can also, at least in part, recapitalize by accessing equity markets. First, if banks can access equity markets, they trade off the costs of doing so against the benefits of being able to maintain a higher volume of lending and lower spreads than they would otherwise be able to do. Second, banks reduce the quantity of loans, which serves to directly limit the deterioration in the MCAR despite the sizeable loss of equity. They are able to do so instantaneously by calling in loans against deposits, in other words by canceling matching financial gross positions. The immediate reduction in loans equals 2.2 percent when banks can only recapitalize through retained earnings, and 0.9 percent when they can also recapitalize by accessing equity markets. Third, banks increase lending spreads, and thereby start to earn additional returns that over time return their equity to the original level. This also allows the volume of lending to start increasing again. The immediate increase in spreads equals 2.1 percentage points when banks can only recapitalize through retained earnings, and 1.0 percentage points when they can also recapitalize by accessing equity markets.

The driving force for banks following the shock is their incentive to escape the danger zone near their regulatory MCAR. The different behavior of the quantity and price of lending under the two scenarios is therefore explained by the fact that access to equity markets allows banks to rebuild their capital adequacy more easily, by being able to resort to some equity issuance instead of lending reductions in the immediate aftermath of the crisis, and by being able to rebuild their previous level of equity and thus lending activity by continuing to issue equity, rather than being limited to earning all equity through higher lending spreads.

When banks can only recapitalize through retained earnings, the combination of lower lending and higher spreads leads to a marked real contraction, with GDP dropping by more than 2 percent by the end of the first year, consumption by almost 3 percent, and investment by almost 5 percent. The collapse in demand leads to lower inflation, with CPI inflation dropping by around 0.6 percentage points by the end of the first year, and the policy rate responding through a drop of around 1 percentage point. This is accompanied by nominal and real exchange rate depreciation, and a trade surplus that grows by over 1 percent relative to GDP. Asset prices drop by over 5 percent on impact, as lower lending and higher spreads lead to a reduced value of ongoing capital projects. The drop in the value of lending collateral is even larger, and more persistent, as reduced levels of investment reduce the capital stock by 0.8 percent after three years.

At the time the shock hits the banking system, banks experience a spike in loan losses equal to around 0.2 percent of the value of their portfolio. These loan losses are due to losses in the value of borrowers' collateral, following the drop in asset prices, and due to foreign exchange losses among borrowers that have borrowed in foreign currency, following the exchange rate depreciation. Most of these losses are, within one quarter, more than compensated by an increase in lending spreads, so that the main effect on capital adequacy ratios is due to the exogenous shock to equity itself. But it should be stressed that what is happening here is deterioration in the performance of loans that is entirely due to a shock to banks' balance sheets, rather than a direct shock to borrowers' balance sheet or creditworthiness. In other words, loans become non-performing due to the emergency measures that banks are forced to take in response to their own equity losses, not due to inherent weaknesses of the borrowers themselves. Through their balance sheet links, the fates of banks and borrowers are therefore highly intertwined, and each one of them can become a victim of shocks to the other.

When banks have the additional option of accessing equity markets, under the particular calibration chosen in this paper, the deterioration in the quantity and price of lending is roughly half as large as when they do not have this option. However, given the nonlinear effects of shocks to balance sheets, this translates into real effects that are significantly less than half as large as under the scenario where banks can recapitalize through retained earnings only, with GDP dropping by 0.8 percent at the lowest point compared to 2.2 percent, and inflation declining by 0.2 percent instead of 0.6 percent. Any macroprudential policies that can reassure potential bank equity investors during a crisis[13] can therefore have disproportionately large benefits by reducing such nonlinearities in the financial sector.

B. Permanent Increase in Minimum Capital Adequacy Ratio

In this simulation, shown in Figure 8, the central concern is again bank capital adequacy. In this case, though, the concern does not arise because of bank losses whereby bank equity becomes suboptimal under given capital adequacy regulations, but rather because of a tightening in capital adequacy regulations whereby banks' previously adequate level of equity becomes insufficient. Specifically, Figure 8 simulates the effects of a permanent increase in the MCAR from 8 percent to 10 percent. The emphasis is both on the long-run effects of this policy and on how the short-run effects depend on the speed at which the new policy is implemented.

To study the latter, we compare three different assumptions. In the first scenario, represented by the black solid line, the MCAR immediately jumps from 8 percent to 10 percent. In the second scenario, represented by the red dashed line, the MCAR is raised by the same amount, but gradually over a period of four years, with most of the increase (1.7 out of 2.0 percentage points) occurring over the first two years. In the third scenario, represented by the blue dash-dotted line, a future increase in the MCAR is announced, with the increases starting after two years and thereafter following the same pattern as in the second scenario. The exact numerical paths for the MCAR are reported in Table 7. In all simulations, banks are assumed to have no access to equity markets, so that all changes in equity are solely due to higher earnings.

The long-run effects of higher MCAR are of course identical across the three scenarios. A higher steady state level of equity, for a given proportional dividend policy, requires permanently higher earnings, and therefore permanently higher spreads, which in our calibration rise by about 30 basis points in the very long run. This reduces the incentive to borrow and invest, and at the same time the demand for the purchasing power needed to support investment, while also raising the opportunity cost of holding that purchasing power. The result is an approximately 2 percent decline in the size of banks' loan and de-

[13] There is empirical evidence that banks have less difficulty in accessing equity markets during economic expansions; see Yang and Tsatsaronis (2012).

posit levels. Permanently lower investment translates into permanently reduced potential output, which drops by around 0.8 percent.

We begin our discussion of the short-run effects with the first scenario (black solid line), which shows the effects of an immediate 2 percentage points increase in the MCAR. Under this scenario banks have been operating with perfectly acceptable equity buffers, but are now, from one day to the next, told that they are undercapitalized to the tune of 2 percent of their assets. This starts a scramble by banks to improve their capital adequacy ratios as soon as possible, because the danger of costly violations of capital adequacy regulations is suddenly far larger than before. Banks take one measure that immediately improves their capital adequacy ratio without requiring additional equity, namely an immediate reduction in the volume of their loans of over 3 percent. Their other response to higher MCAR is to build up their equity over time, through an increase in spreads that equals around 2 percentage points on impact. This scramble by banks to improve their balance sheets is ultimately successful, however it initially has very detrimental effects on the balance sheets of their borrowers, with real asset prices declining by around 8 percent on impact. As a result, banks make lending losses equal to around 0.4 percent of the value of their assets. On impact these lending losses are, due to the predetermined nature of lending rates, not fully compensated by increases in lending spreads. The immediate effect of the higher MCAR is therefore to reduce the actual capital adequacy ratio by around 0.2 percent. High spreads at a reduced lending volume subsequently raise banks' capital adequacy ratio, and after around 5 years they manage to build an equity buffer over the new, raised MCAR that is similar to the buffer they had accumulated prior to the change in regulations.

Banks' hurried compliance with the new higher MCAR comes not only at the expense of their borrowers, but also of the economy at large. Higher spreads and a reduction in bank-created purchasing power lead to deep contractions in consumption and investment, with GDP contracting by almost 3 percent towards the end of the first year after the change of policy, with inflation dropping by almost 0.7 percentage points, and the policy rate dropping by 1.7 percentage points. These initial effects are far larger than they need to be, because a more gradual policy change that gives banks time to satisfy the new regulations over time can induce them to change the availability and price of loans far less drastically at the outset. This is illustrated in the two alternative simulations.

Under the unanticipated but gradual increase in MCAR (red dashed line), banks are given more time to accumulate equity without immediately running a much higher risk of violating the regulations. Because they can spread out the accumulation of equity over a two-year period, and because their main means of accumulating equity is higher lending spreads, their spreads therefore no longer need to exhibit a spike on impact. Instead, spreads rise by just over 40 basis points initially, and remain 30 basis points above their previous level thereafter. This pattern of spreads is reflected in the behavior of the actual capital adequacy ratio which, while increasing to restore the desired equity buffer above the MCAR, can increase much more gradually than under the unanticipated scenario. Under the gradual scenario, real bank credit still declines on impact, but less dramatically than under the unanticipated scenario. The decline in real asset prices is only half of that observed under the unanticipated scenario, or around 4 percent. The effects of a more gradual introduction of higher MCAR on the real economy come mostly through a different behavior of consumption, with the amplitude of fluctuations in investment quite similar to the unanticipated scenario. The more gradual reduction of credit and therefore of available purchasing power, and the absence of a spike in lending rates, which determines the cost of producing that purchasing power, permit a much shallower contraction in consumption, with the result that GDP, instead of contracting by almost 3 percent at the lowest point, contracts by around 1.75 percent.

Under the anticipated gradual scenario (blue dash-dotted line) the short-term macroeconomic effects are even more benign. Here lending spreads increase by less than 10 basis points over the initial two-year period prior to the announced increases of the MCAR, and thereafter they rise to similar amounts as under the other two scenarios. The reason for the initial behavior of spreads is that during the first two years banks' cost of making loans, which depends on the then current MCAR, does not actually increase. What does change during this period however is the behavior of investors, who anticipate permanently tighter future lending conditions, and therefore a permanently lower optimal capital stock. Because the capital stock can only be changed gradually, and with adjustment costs on investment, it is therefore optimal for investors to immediately start a period of reduced investment. This process, while slower than under the previous two scenarios due to less drastic changes in lending conditions in the first few quarters, is nevertheless very similar to the other two scenarios over the medium and long run. The reduction in investment demand translates into a lower demand for bank loans. Banks accommodate this change in loan demand, so that their loan book declines by 2 percent prior to the end of the second year. Over this period, it is therefore this reduction in the size of their balance sheet, and not an increase in spreads, that is banks' main strategy for increasing the actual capital adequacy ratio towards its known higher long-run level. Since it would make little sense to quickly build up a large equity buffer over the first two years, when it is not yet needed, the actual capital adequacy ratio exhibits a much slower increase than under the other two scenarios. The effect on real asset prices is also much more benign, they decline by less than 1 percent on impact. As a result of initially much more benign lending conditions, consumption is barely affected by the new policy over the first two years, and the behavior of GDP shows no initial deep recessionary episode. Rather, GDP smoothly declines towards its new and approximately 0.8 percent lower long-run level. Downward pressure on inflation is also far smaller than in the other two scenarios.

This simulation has clearly illustrated another important aspect of well-executed macroprudential policies. The objective of such policies is always to prevent, or to cope with, balance sheet dislocations among banks and their borrowers. The origin of such dislocations is typically a vulnerability that has built up over a number of years. But the trigger is generally a shock to either economic fundamentals or to market expectations concerning fundamentals. However, regulation is itself an integral part of those fundamentals. The way in which it is introduced must therefore be designed in such a way that it does not itself become a source of unexpected shocks. In the case of minimum capital adequacy regulations (and probably for many other policies that affect balance sheets), this calls for gradual and well-communicated implementation, giving market participants time to adjust without unleashing the feedback mechanisms we stress throughout this paper.

C. Shocks to the Cost of Borrowing in International Financial Markets

In Figure 9, we simulate a boom-bust credit cycle driven by shocks to conditions in international financial markets, and study how the vulnerability of the economy to such shocks depends on the currency composition of bank borrowers' balance sheets.[14] Two scenarios are considered, one in which all bank lending is in domestic currency, which is shown as the black solid line and referred to as the "resilient economy" scenario, and another in which 50 percent of all lending is in foreign currency, which is shown as the red dashed line and referred to as the "vulnerable economy" scenario. Both simulations assume a common sequence of shocks to the cost of foreign financing faced by the country.[15] During an initial three-year boom period, which is misperceived as being permanent by all domestic agents, the cost of foreign financing drops by 200 basis points. This is followed by an unanticipated reversal at the end of the third year, when the cost of foreign financing sud-

[14] We recall that banks themselves are always fully hedged in our model.

[15] Whether the cost of foreign financing changes because of a country specific premium or because of world interest rates is largely irrelevant for the simulation results.

denly increases by 300 basis points, to 100 basis points above its original level, followed by a gradual decline back to its original level.

We begin with a description of the features that are qualitatively similar across the two scenarios. The initial shock leads to an immediate real exchange rate appreciation of approximately 5 percent, followed by a gradual subsequent real depreciation. This allows the domestic real interest rate to decrease more gradually than the foreign rate, with the nominal policy rate falling over time in response to the drop in inflation triggered by the real appreciation. Lower real interest rates, together with the positive wealth effects of an appreciated currency, lead to a boom in investment, accompanied by an increase in asset prices. Higher investment demand requires higher bank loans and the higher purchasing power generated by such bank loans, and higher asset prices increase the value of collateral that is available to support such lending. As a result, domestic lending increases by 4 to 5 percent by the end of the third year, and spreads decrease, at least initially.

These impact effects on lending, but especially on spreads, are much stronger in the vulnerable economy scenario, because in that case the domestic currency value of existing foreign debt declines on impact, thereby raising the net worth and thus the borrowing capacity of households much further. These differences between scenarios are reflected in the real economy. In both scenarios, real GDP expands by about 3 percent by the end of year three, consumption by just under 2 percent, and investment by almost 15 percent. But due to the greater relaxation of lending terms in the vulnerable economy scenario, this simulation exhibits a much stronger initial boom phase, especially in consumption. Inflation immediately declines in the resilient economy scenario, as the currency appreciation outweighs the effects of additional demand, while in the vulnerable economy scenario inflation does not start to decline until the second year, because the increase in demand is so much stronger. The trade balance deteriorates in both scenarios, but again especially in the vulnerable economy scenario. This leads to the accumulation of significant claims on the domestic economy by foreigners, in other words to a capital inflow.

We emphasize that the foreign shock that triggers these developments is an initial reduction in the cost of foreign financing, and not an initial inflow of foreign capital that can subsequently be intermediated by domestic banks, thereby permitting them to make additional domestic loans. The story of the capital inflow as the primary shock is in fact a physical and logical impossibility, because it suggests that foreign residents can deposit real resources in a domestic bank in exchange for a deposit, with these resources then becoming available for lending to domestic residents. Neither banks nor any other financial institutions are in the business of directly intermediating real resources, they are in the business of creating (or, in the case of non-bank financial intermediaries, intermediating) the purchasing power that allows non-banks to trade real resources among themselves. The role of banks in the trade balance deterioration in Figure 9 is therefore as the creators of additional purchasing power for domestic residents, which is then used by those residents, in part, to purchase foreign goods. As this purchasing power ends up in the hands of foreign sellers of goods, foreign debt increases, and this is the capital inflow. The capital inflow is therefore a consequence of additional bank lending, and not vice versa. The fact that the boom is not created by a capital inflow, but by increased domestic lending in response to foreign (or domestic) price incentives, is critical for formulating policy advice on how to deal with such episodes.

The reversal of the boom leads to a large real exchange rate depreciation. In the vulnerable economy this relative price change is not only larger, but by increasing the domestic currency value of foreign currency loans, it also has a strong negative effect on the net worth, and therefore on the riskiness and borrowing capacity, of households. By contrast, in the resilient economy it has almost no effect on their borrowing capacity. As a consequence, the post-reversal phases of these two economies differ greatly.

We begin our discussion of post-reversal dynamics with the resilient economy. The foreign real interest rate rises suddenly and dramatically, and the domestic real interest rate also starts to rise, but more gradually, with the wedge between the two rates determined by the real exchange rate appreciation that sets in immediately after the reversal. Higher real interest rates imply an immediate drop in investment demand, with output following suit. The reduced level of real activity leads to a lower demand for bank financing and bank deposits, which implies that real bank credit goes on a similar downward trajectory as GDP. Lending spreads, which by the time of the reversal had increased to around 20 basis points above their initial value, because banks had expanded credit to include a larger share of riskier borrowers, now start to decline as banks cut funding to such borrowers. However, the most important aspect of this simulation is that, at the time of the reversal, there is only a very small increase in borrower defaults and thus in bank losses. While the small (less than 2 percent) decline in real asset prices hurts borrower balance sheets, the absence of foreign currency balance sheet exposures provides protection against the much larger depreciation of the real exchange rate. And domestic real interest rates do not change dramatically on impact, which in turn helps to limit the drop in real asset prices. As a result of small lending losses, banks' capital adequacy ratio remains almost unchanged, so that they are not forced to cut lending or raise spreads precipitously to improve their balance sheets.

This means that banks generate very little additional downward momentum to the economy, beyond what is implied by the reversal in foreign interest rates itself. As a result, GDP declines smoothly without large negative output gaps, and inflation quickly returns to its target, facilitated by the depreciated exchange rate.

For the vulnerable economy the situation is very different. Here borrowers' net worth is severely impaired, as the real value of their foreign currency liabilities increases with the real depreciation. This leaves banks exposed to a loan book that is much riskier than anticipated when it was first made, so that they make large loan losses equal to around 0.8 percent of the value of their loan book, with their capital adequacy ratio deteriorating by a similar amount. They immediately tighten lending terms, both to be sufficiently compensated for higher lending risk and to shore up their own balance sheet. Specifically, they reduce lending immediately by almost 4 percent, and increase spreads by almost 2 percentage points. This creates a vicious cycle, because higher spreads and a sudden contraction in lending lead to a much more severe contraction in real demand, an even larger real depreciation, and a very severe drop in asset prices of over 8 percent. This vicious cycle keeps spreads elevated, and lending depressed, for several years. The collapse in investment is deep and almost instantaneous, and GDP drops by almost 5 percent within a year of the reversal. The drop in demand is so large that inflation keeps falling for another year, despite the large depreciation, with the policy rate following suit to contain the downturn.

This simulation contains another important lesson for macroprudential policy. We have seen that when domestic borrowers are exposed to significant foreign currency risk, a shock that depreciates the exchange rate can give rise to large balance sheet dislocations that can be similar in nature and magnitude to those following the collapse of a domestic asset price bubble, see subsection III.C. For both types of shocks, as discussed in subsection IV.C, policy can respond by tightening macroprudential regulations during the boom, and relaxing them during the reversal. In the case of domestic asset price bubbles there are few other options, because expectations cannot be legislated, and furthermore because it may not be wise for the policymaker to engage in second-guessing as to whether an asset price boom is based on fundamentals or not. But in the case of foreign currency exposures there is an additional option – the direct prudential regulation of currency mismatches on domestic balance sheets. Our simulation in this subsection has shown that the costs of such mismatches are highly nonlinear when things go wrong. This is therefore a policy tool worth considering.

VI. CONCLUSION

In this paper we have studied the simulation properties of MAPMOD, a new model that has been designed to study vulnerabilities associated with excessive credit expansions, and to support macroprudential policy analysis. The critical feature of the model is that banks play a far more active role in the macroeconomic transmission mechanism than in the traditional loanable funds model. Banks in MAPMOD, and in the real world, do not have to wait for deposits to arrive before using those deposits to fund loans. Rather, they create new deposits in the process of making new loans, and these deposits serve as the economy's principal medium of exchange. In other words, so long as banks are adequately capitalized, and expect lending to be sufficiently profitable, they can quickly expand (or, in downturns, contract) their balance sheets. This can be beneficial if banks' assessment of economic conditions is accurate. But if their assessment is too optimistic, the growth of bank and borrower balance sheets can build up large vulnerabilities that, as soon as the economy experiences negative shocks, can be revealed in a deep financial crisis that has severe and highly nonlinear effects on the real economy. A distinguishing feature of such crises is that banks' response to deteriorating economic conditions does not come mainly in the form of higher lending spreads, although this does play a role, but rather in the form of severe cutbacks in lending.

A major strength of the model is its ability to simulate a wide variety of policy-relevant scenarios that have an important financial-sector dimension, and that take into account the critical nonlinearities associated with balance sheet problems. We have simulated shocks to (actual or expected) productivity growth, to the riskiness of bank borrowers, to deviations of asset prices from their fundamental values, to bank equity, and to foreign interest rates. We have also simulated changes in macroprudential policies, including increases in minimum capital adequacy ratios and changes in the countercyclicality of bank capital requirements.

It is important to emphasize that MAPMOD is a prototype simulation model whose parameters have been calibrated to match the basic facts of financial cycles. The existence of nonlinearities, and of evolving financial sector policies to guard against financial crises, poses some very difficult estimation issues. It is well known that the estimation of nonlinear models can require much larger sample sizes to identify functional forms and to detect the existence of nonlinearities. This small sample size problem is particularly challenging for models designed for macroprudential policy analysis, for two reasons. First, as we have demonstrated, nonlinearities can be especially severe when modeling the financial sector.

Second, to the extent that macroprudential policies based on models such as MAPMOD end up being successful at preventing large boom-and-bust financial cycles, this will severely limit the number of empirical observations that are available for estimation.[16] In choosing the best structure and parameterization of the model, we are therefore likely to have to continue to rely heavily on judgment informed by a reading of existing empirical evidence across many economies, rather than on formal estimation based on a single data set for a particular country.

[16] See Committee on the Global Financial System (2010).

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Appendix A. Parameterization

The parameterization of the model is for illustrative purposes only. While it is largely based on the authors' experience with developing and using models to support policy making in a large number of countries, it does not refer to a particular empirical data set. When interpreting the simulation results, the readers should therefore not draw any *direct quantitative* inferences or policy implications. In particular, the quantitative properties of the model when subjected to large shocks will contain enormous uncertainty around them. As we argue in the companion paper (Benes, Kumhof, and Laxton, 2014), a great amount of such uncertainty, uncertainty or ambiguity in the true Knightian sense, will always remain unresolved (and unresolvable) no matter what empirical methods are used. This does not, by any means, underplay the role of models in macroprudential policy. Quite the contrary, as argued by Hansen (2012), "an important role for economic modeling is to provide an interpretable structure for using available data to explore the consequences of alternative policies in a meaningful way."

The real sector is calibrated to depict a typical emerging market economy with high shares of exports and imports in GDP, flexible access to the international financial markets, and autonomous monetary policy with a floating exchange rate. The various dynamic persistence parameters (habit, adjustment costs, etc.) are calibrated so to achieve a realistic trade-off between nominal and real volatility in the short and medium run (represented by system properties such as the sacrifice ratio), plausible pass-through of the exchange rate into domestic prices, and time distributed expenditure switching effects reflecting constraints in the short-term substitutability between local production and imports, typical of small open economies. In the baseline calibration, we also assume a 50% dollarization of financial liabilities (bank loans) held by non-financial agents (households); as explained in the theory paper, banks remain *unexposed* to direct currency mismatches, owing to simple hedging strategies based on shorting or longing forwards. Furthermore, in some simulation experiments, we also explicitly compare results for different degrees of financial dollarization.

The main guidance in calibrating the macrofinancial parameters was provided by the simulation experiments themselves. We used casual observations on the relationships between external financial shocks and responses in the domestic economy observed in some emerging market economies during 2008–2009, with the country risk premium simulation being an example thereof. Furthermore, we calibrated the credit risk characteristics that would give rise to major financial instabilities with troughs in real economic activity (GDP and domestic demand) ranging roughly between 5 and 10 % relative to the level preceding the adverse event.

The individual parameter values used for the simulation experiments (with deviations from these baseline values described in the text, should there occur) are listed in Table 1. We also provide a brief overview of selected steady-state characteristics implied by the calibration in Table 2.

Systematizing the international empirical evidence on quantitative characteristics of macro-financial feedback mechanisms, and enhancing eventually the utility of macroprudential policy models is addressing real-world issues, will be one of the main lines of our further research.

Table 1. Baseline Parameter Values

	Parameters Affecting Steady State	
β	Discount parameter	0.966
β'	Reduced discount parameter	0.955
λ	Loss given default	0.9
ς	Total credit risk	0.21
$\hat{\varsigma}$	Prediction of total credit risk	0.21
ϱ	Cross-correlation of exposures	0.21
ϕ_C	Financing of consumption	1.46
ϕ_I	Financing of investment	1.46
ϕ_K	Financing of physical capital	0.1
α	Domestic labor in exports	0.3
η	Inverse elasticity of labor supply	0
δ	Depreciation of physical capital	0.025
γ_N	Labor share of domestic production	0.4
γ_M	Import share of domestic production	0.2
μ	Monopoly power	1.2
κ	Location parameter for stochatic default threshold	0.74
ω	Direct import in final demand	0
ν	Local ownership of banks	0
	Policy parameters	
φ	Minimum capital adequacy ratio	0.08
υ	Regulatory penalty	0.06
π	Inflation target	0
θ_1	Monetary policy smoothing	0.8
θ_2	Monetary policy reaction to inflation	4
	Other Parameters	
ι	Non-price lending conditions response	0.2
ξ_E	Bank capital adjustment cost	∞
χ	Consumption habit	0.85
ξ_C	Current income dependence	0.5
ξ_W	Wage adjustment cost	300
ξ_P	Price adjustment cost	300
ξ_Y	Input factor adjustment cost	30
ξ_X	Export adjustment cost	30
ξ_I	Investment adjustment cost	5
o	Financial dollarization	0.5

Table 2. Selected Steady-State Characteristics[17]

Banking	
Capital adequacy ratio	11.41 %
Capital buffers	3.41 %
Capital-to-assets ratio (not adjusted)	10.98 %
Lending spread	2.37 %
Individual risk component of lending spread	1.22 %
Regulatory component of lending spread	1.13 %
Bank-deposits-to-GDP-ratio	56 %
Real economy	
Total-consumption-to-GDP ratio	79 %
Business-investment-to-GDP ratio	19 %
Export-to-GDP ratio	62 %
Share of value added in exports	30 %
Net-exports-to-GDP ratio	2 %
Foreign-debt-to-GDP ratio	20 %

[17]All steady-states rates of interest and flows-to-stock ratios are annualized.

Appendix B. Numerical Assumptions for Simulations

Table 3. Revisions in Views About Trend Productivity Growth – Assumptions

Quarter	0	1	2	3	4	5	6	7	8	9	10	11	12
(1)	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.7	1.9	2.1	2.3
(2)	0	0.2	0.7	1.1	1.5	1.9	2.3	2.6	3.0	3.4	3.8	4.2	4.6
(3)	0	0.2	0.7	1.6	2.2	2.7	3.3	3.8	4.4	5.0	5.5	6.1	6.7
(4)	0	0.2	0.7	1.6	2.8	3.5	4.3	5.0	5.7	6.4	7.2	7.9	8.7
(5)	0	0.2	0.7	1.6	2.8	3.5	4.3	5.0	5.7	6.4	7.2	7.9	8.7
Quarter	13	14	15	16	17	18	19	20	21	22	23	24	∞
(1)	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	8.0
(2)	4.9	5.3	5.7	6.1	6.5	6.9	7.3	7.7	8.1	8.5	8.9	9.3	16.0
(3)	7.2	7.8	8.4	9.0	9.6	10.2	10.8	11.4	12.0	12.6	13.2	13.8	24.0
(4)	9.4	10.2	11.0	11.7	12.5	13.3	14.1	14.9	15.7	16.5	17.3	18.1	32.0
(5)	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7

1. Level of export productivity as expected in quarter 1, $100 \log\left(A_{X,t}/A_{X,0}\right)$.

2. Level of export productivity as expected in quarter 2, $100 \log\left(A_{X,t}/A_{X,0}\right)$.

3. Level of export productivity as expected in quarter 3, $100 \log\left(A_{X,t}/A_{X,0}\right)$.

4. Actual level of export productivity no downward revisions, $100 \log\left(A_{X,t}/A_{X,0}\right)$.

5. Level of export productivity after downward revisions, $100 \log\left(A_{X,t}/A_{X,0}\right)$.

Table 4. Underpricing of Lending Risk by Banks ("NINJA Loans" Shock) – Assumptions

Quarter	0	1	2	3	4	5	6	7	8	9	10	11	12
(1)	21.0	20.9	20.8	20.8	20.7	20.6	20.5	20.4	20.3	20.2	20.2	20.1	20.0
(2)	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
(3)	21.0	20.9	20.8	20.8	20.7	20.6	20.5	20.4	20.3	20.2	20.2	20.1	20.0
(4)	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
Quarter	13	14	15	16	17	18	19	20	21	22	23	24	∞
(1)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
(2)	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
(3)	20.1	20.2	20.3	20.3	20.4	20.5	20.5	20.6	20.6	20.7	20.7	20.7	21.0
(4)	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0

1. Standard deviation of the log return on collaterizing assets assumed by banks in the "NINJA1" scenario, $100\widehat{\varsigma}_t$.

2. Actual standard deviation of the log return on collaterizing assets in the "NINJA1“ scenario, $100\varsigma_t$.

3. Standard deviation of the log return on collaterizing assets assumed by banks in the "NINJA2" scenario, $100\widehat{\varsigma}_t$.

4. Actual standard deviation of the log return on collaterizing assets in the "NINJA2" scenario, $100\varsigma_t$.

Table 5. Excessive Credit Expansion Caused by an Asset Price Bubble – Assumptions

Quarter	0	1	2	3	4	5	6	7	8	9	10	11	12
(1)	0	0.4	1.1	1.8	2.6	3.5	4.4	5.3	6.2	7.1	8.0	9.0	9.9
(2)	0	0.4	0.8	1.2	1.7	2.1	2.5	2.9	3.3	3.8	4.2	4.6	5.0
Quarter	13	14	15	16	17	18	19	20	21	22	23	24	∞
(1)	0	0	0	0	0	0	0	0	0	0	0	0	0
(2)	-4.9	0	0	0	0	0	0	0	0	0	0	0	0

1. Asset price bubble, $100\log(B_t/B_0)$.

2. Unanticipated shocks to the bubble process, $100\epsilon_{B,t}$.

Table 6. Countercyclical Macroprudential Policy – Assumptions

Quarter	0	1	2	3	4	5	6	7	8	9	10	11	12
(1)	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
(2)	8.0	8.0	8.1	8.2	8.5	8.8	9.0	9.2	9.3	9.4	9.4	9.5	9.5
Quarter	13	14	15	16	17	18	19	20	21	22	23	24	∞
(1)	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
(2)	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0

1. Constant minimum capital adequacy ratios, $100\,g_t$.

2. Countercyclical minimu capital adequacy ratios, $100\,g_t$.

Table 7. Permanent Increase in Minimum Capital Adequacy Ratio – Assumptions

Quarter	0	1	2	3	4	5	6	7	8	9	10	11	12
(1)	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
(2)	8.0	8.4	8.7	9.0	9.2	9.3	9.5	9.6	9.7	9.7	9.8	9.8	9.9
(3)	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.4	8.7	9.0	9.2
Quarter	13	14	15	16	17	18	19	20	21	22	23	24	∞
(1)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
(2)	9.9	9.9	9.9	9.9	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
(3)	9.3	9.5	9.6	9.7	9.7	9.8	9.8	9.9	9.9	9.9	9.9	9.9	10.0

1. Unanticipated immediate increase in minimum capital adequacy ratios, $100\,g_t$.

2. Unanticipated gradual increase in minimum capital adequacy ratios, $100\,g_t$.

3. Anticipated gradual increase in minimum capital adequacy ratios, $100\,g_t$.

Table 8. Shocks to the Cost of Borrowing in International Financial Markets – Assumptions

Quarter	0	1	2	3	4	5	6	7	8	9	10	11	12
(1)	0	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Quarter	13	14	15	16	17	18	19	20	21	22	23	24	∞
(1)	1.00	0.50	0.25	0.12	0.06	0.03	0.02	0.01	0.00	0.00	0.00	0	0

1. Cost of world finance (non-resident bank liabilities), $100\left[\left(R_t^*/R_0^*\right)^4-1\right]$.

APPENDIX C. FIGURES WITH SIMULATION RESULTS

Figure 1. Revisions in Views About Trend Productivity Growth

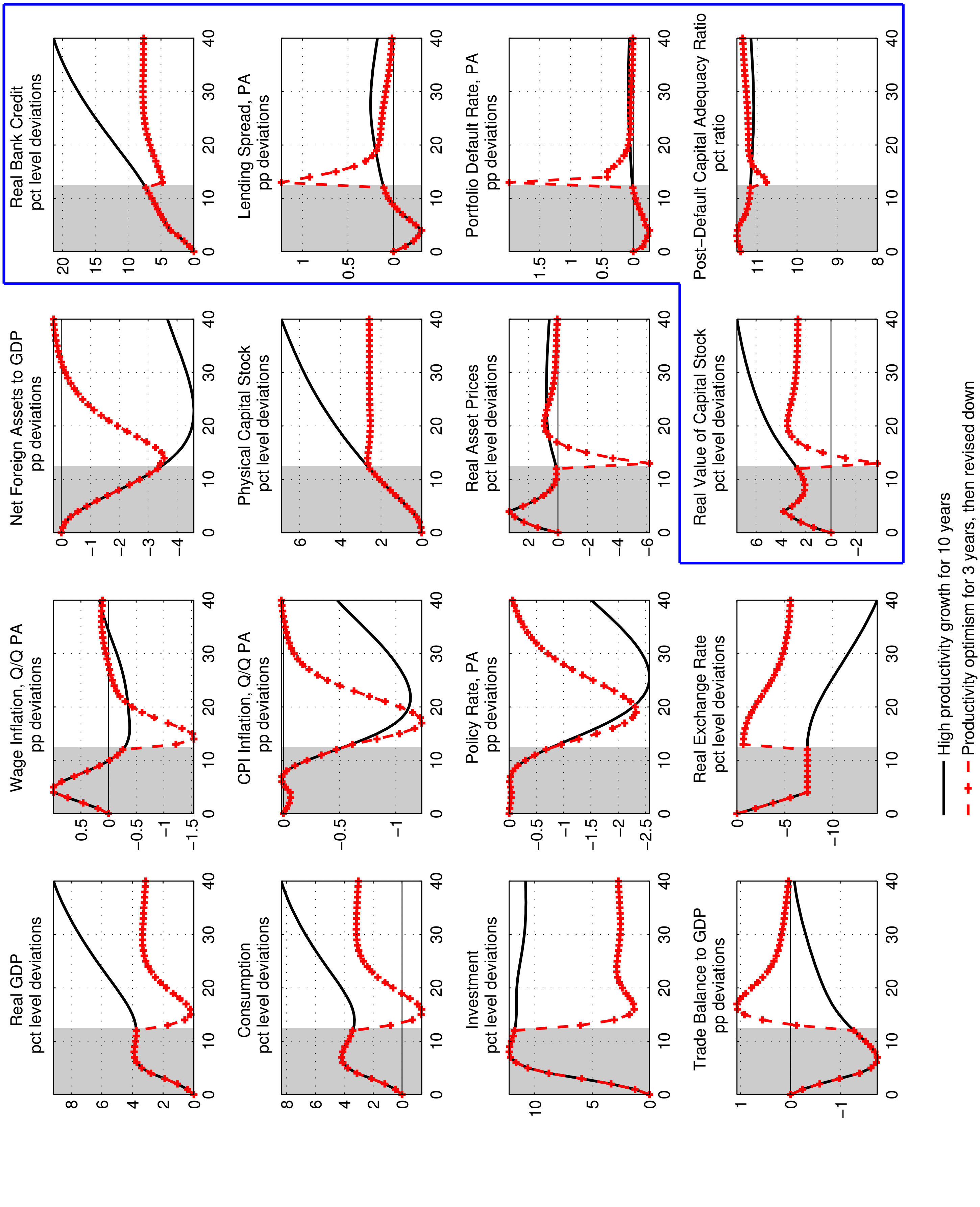

Figure 2. Underpricing of Lending Risk by Banks ("NINJA Loans" Shock)

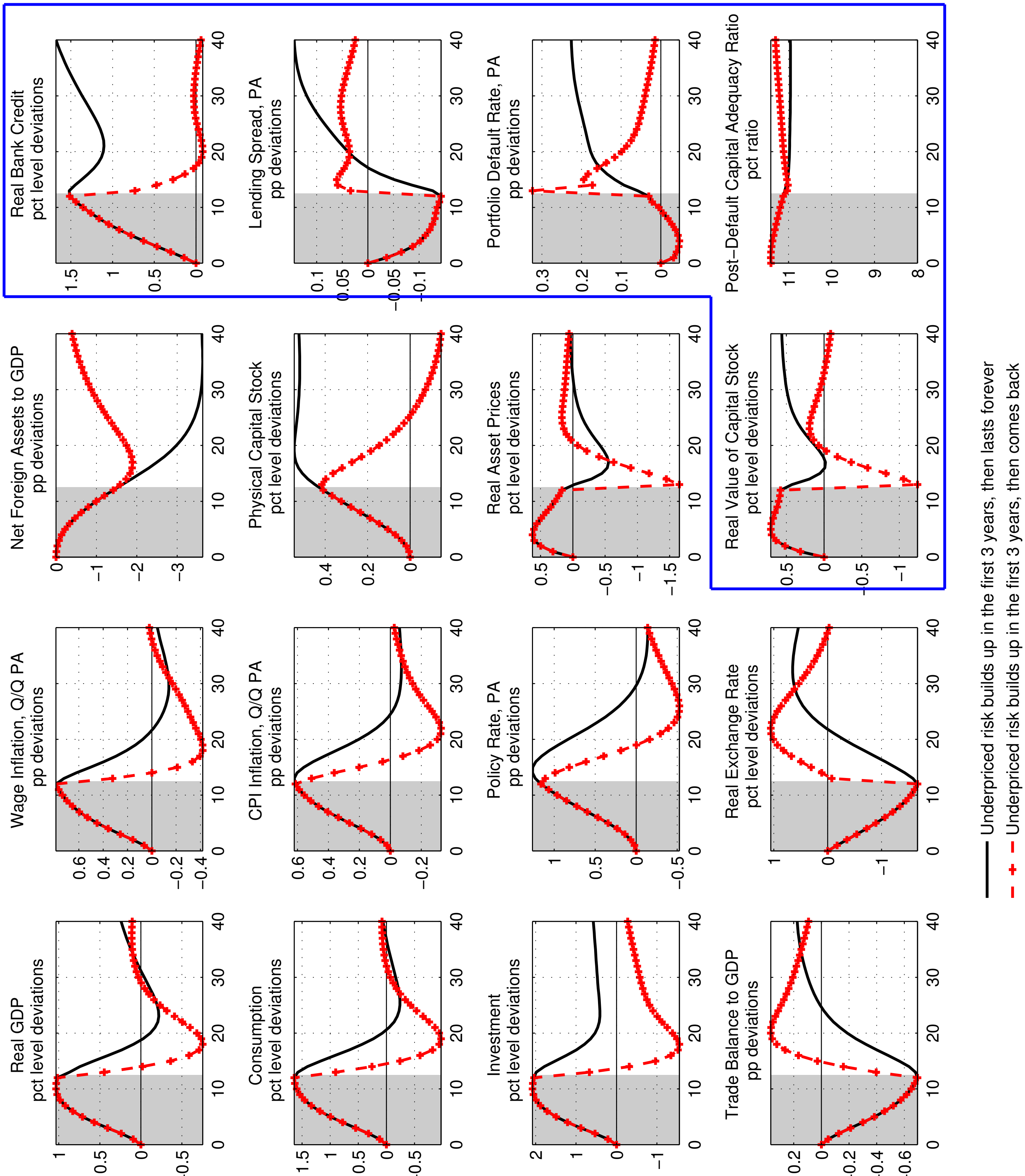

Figure 3. Excessive Credit Expansion Caused by an Asset Price Bubble

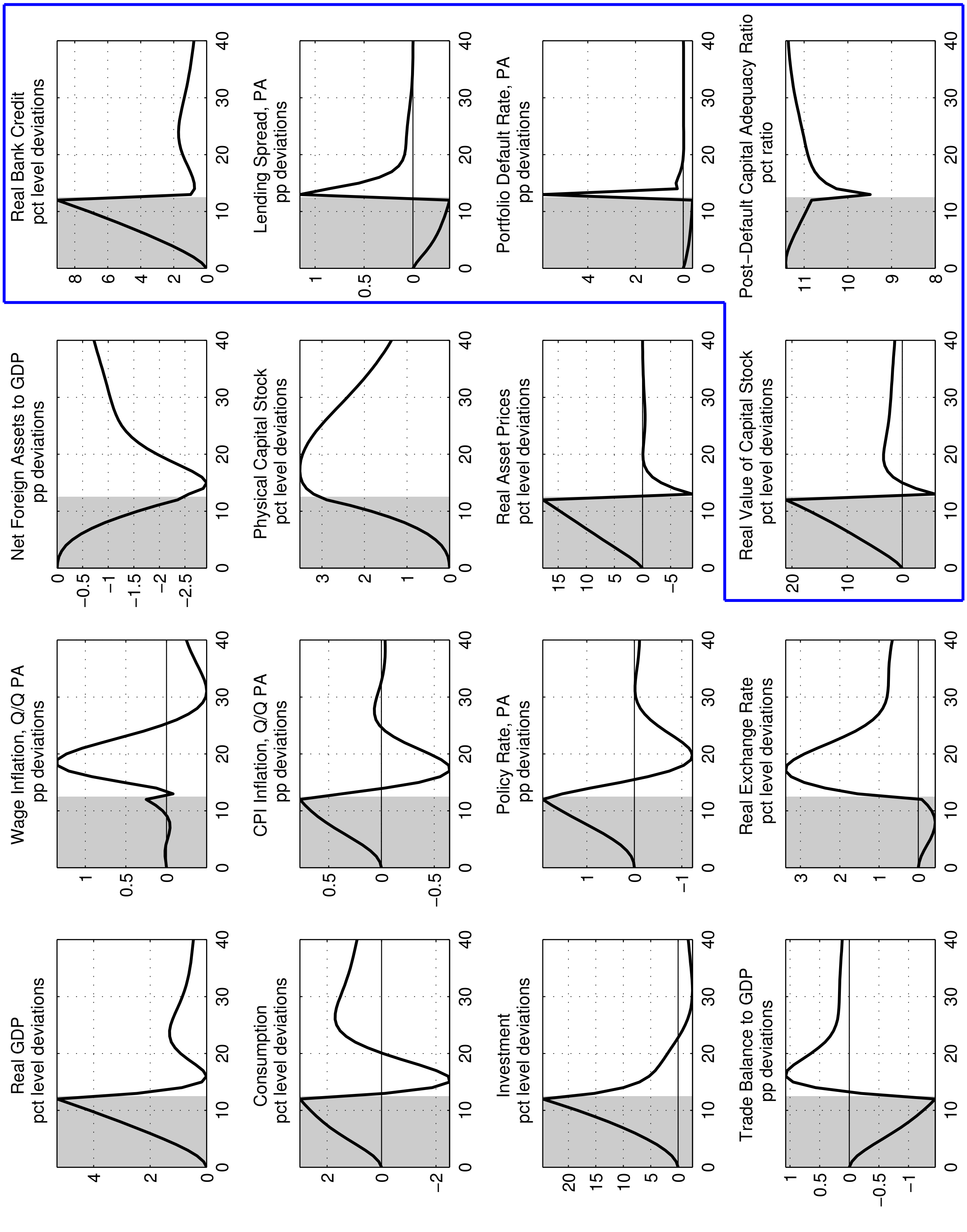

Figure 4. Financial Sector Vulnerabilities and Financial Crises

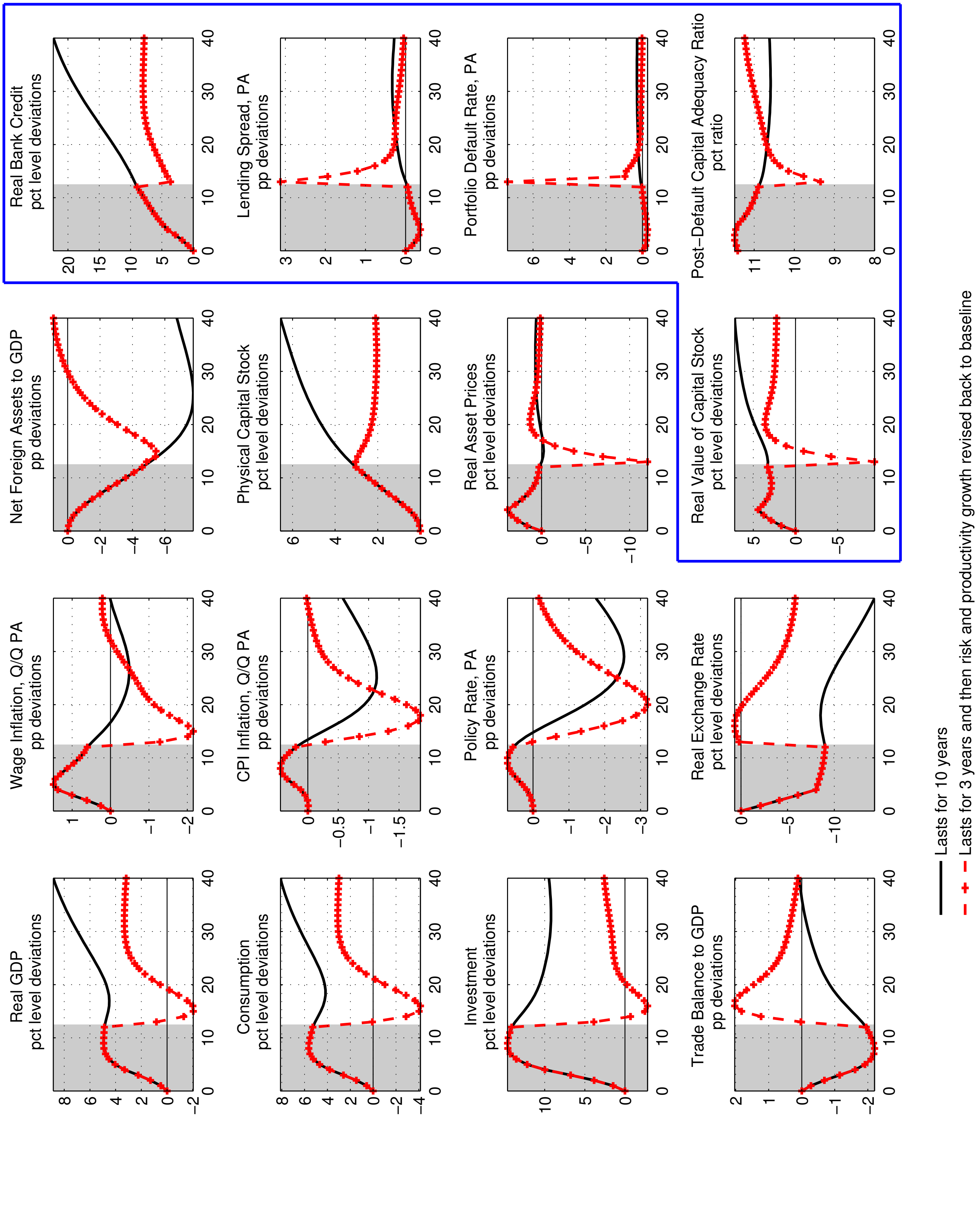

Figure 5. Nonlinear versus Linear Simulations

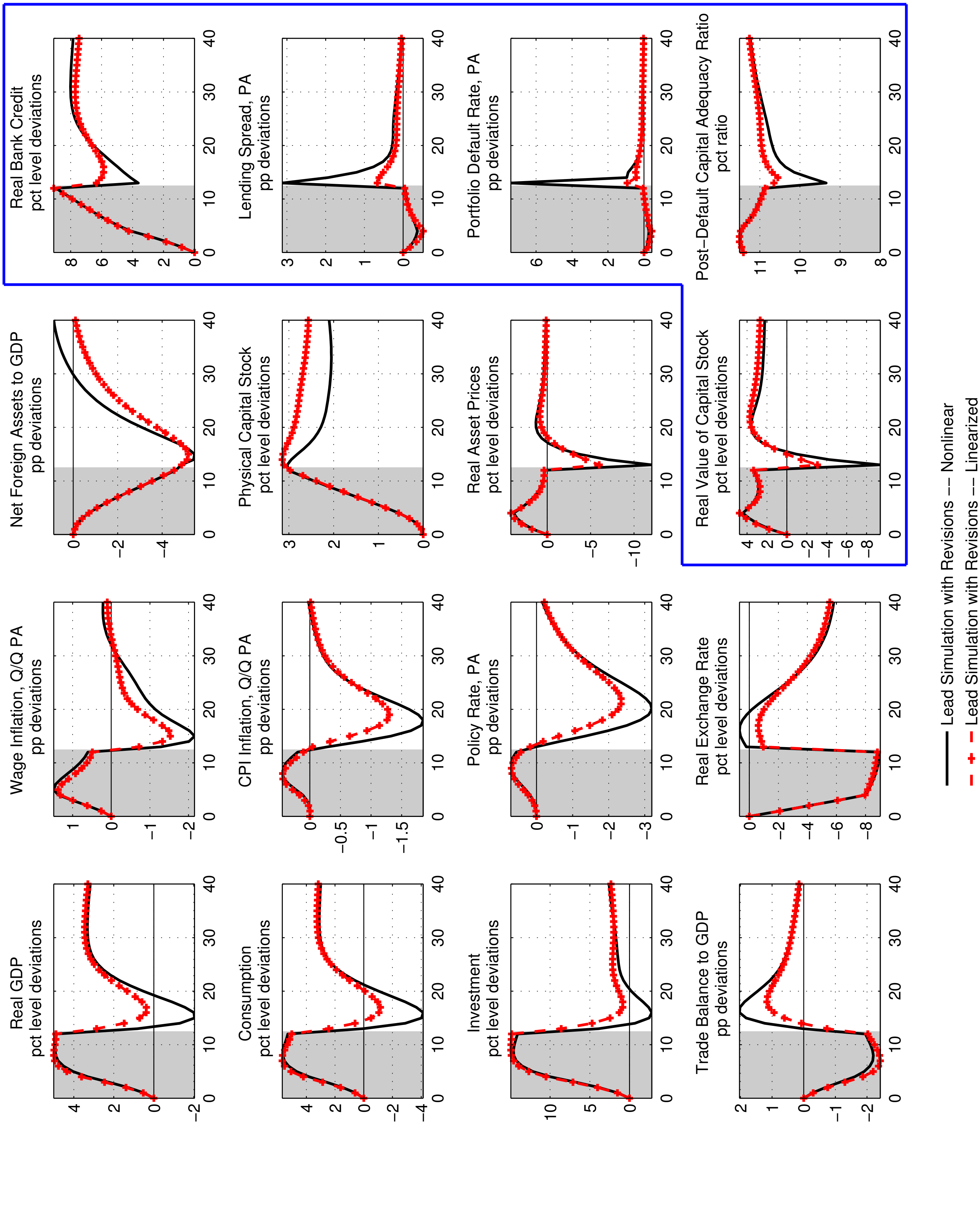

Figure 6. Countercyclical Macroprudential Policy

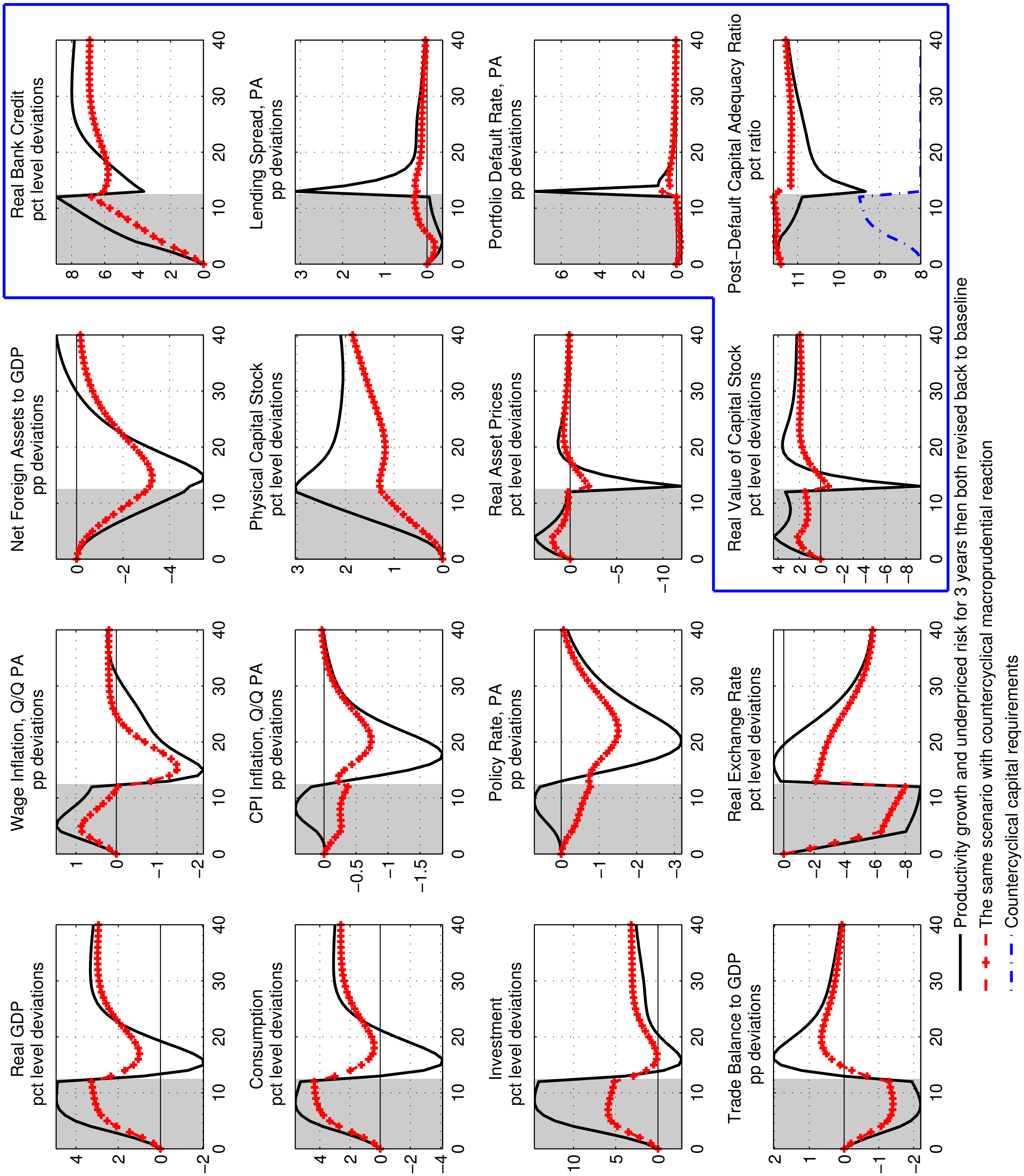

Figure 7. Contractionary Shock to Bank Capital

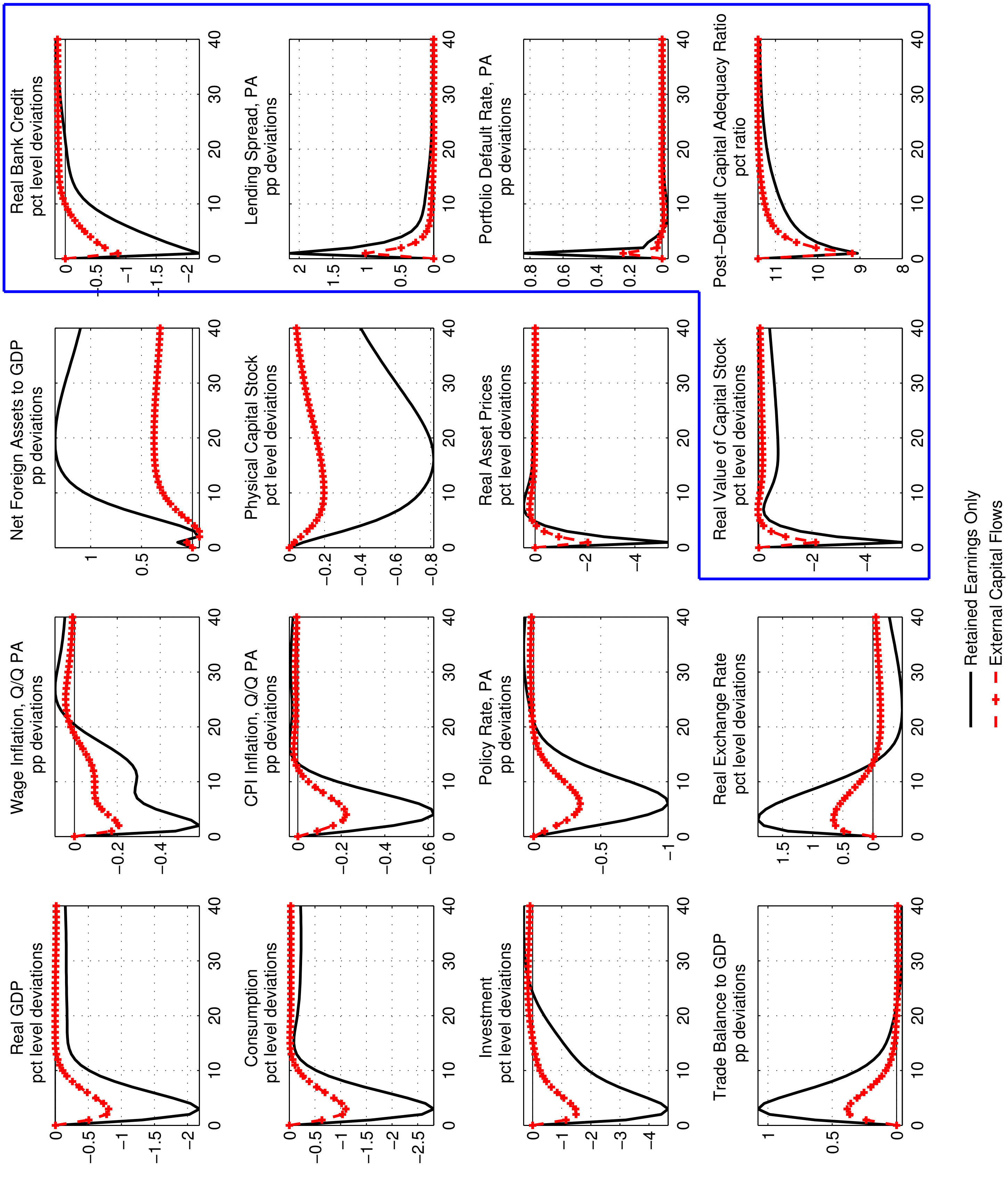

Figure 8. Permanent Increase in Minimum Capital Adequacy Ratio

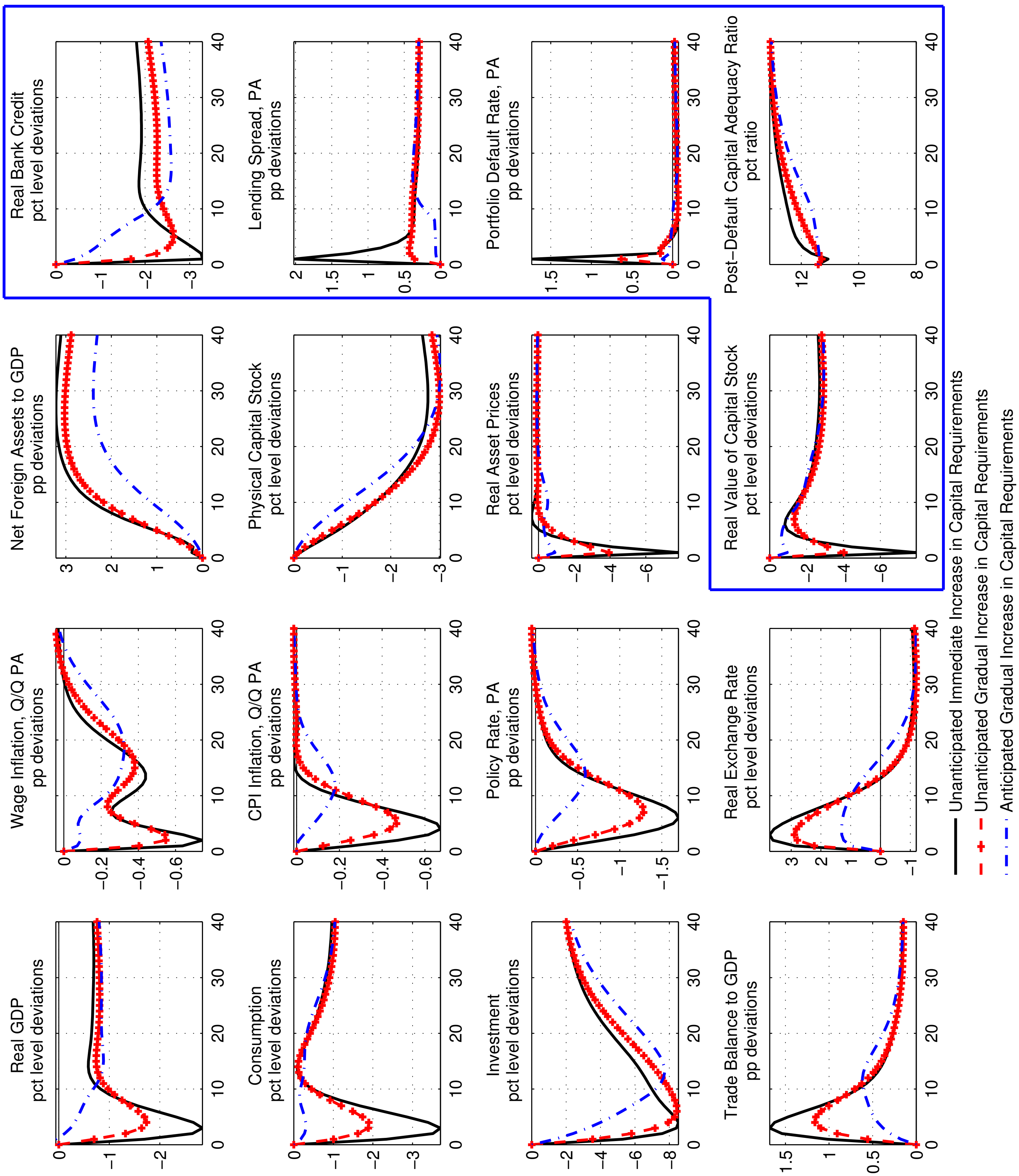

Figure 9. Shocks to the Cost of Borrowing in International Financial Markets