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Hiona Balfoussia
Heather D. Gibson
Dimitris Malliaropulos
Dimitris Papageorgiou

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BANK OF GREECE
Economic Analysis and Research Department – Special Studies Division
21, E. Venizelos Avenue
GR-102 50 Athens
Tel: +30210-320 3610
Fax: +30210-320 2432

www.bankofgreece.gr

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THE ECONOMIC IMPACT OF PANDEMICS: REAL AND FINANCIAL TRANSMISSION CHANNELS

Hiona Balfoussia
Bank of Greece

Heather D. Gibson
Bank of Greece

Dimitris Malliaropulos
Bank of Greece and University of Piraeus

Dimitris Papageorgiou
Bank of Greece

Abstract

We explore the economic impact of the pandemic and the importance of real and financial sector linkages in this context. We explicitly model the financial sector and trace its role in propagating the pandemic shocks. We find that the pandemic-induced adverse labour supply shock can have sizable effects on the real economy, which are further propagated through the banking sector. Moreover, the contemporaneous pandemic-induced financial shock has financial, but also real effects, including high and protracted firm bankruptcies as well as a more fragile banking sector, thus hindering the financing of the real economy. The duration of the pandemic matters for its impact on the macroeconomy, as both business investment and bank balance sheets take disproportionately longer to recover. Our findings underline the need for well-targeted policy measures to support the real economy and, secondarily, the financial sector during the pandemic and provide justification for several of the policy initiatives recently taken by governments, central banks and regulatory institutions around the world.

Keywords: COVID-19, pandemic, lockdown, social distancing, uncertainty, propagation

JEL classification: E2, E3, E5, G1

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Correspondence:
Dimitris Malliaropulos
Economic Analysis and Research Department,
Bank of Greece,
21 El. Venizelos Av.,
10250 Athens, Greece
Tel.:0030-210-3202380
Fax: 0030-210-3203939
Email: dmalliaropulos@bankofgreece.gr

1. Introduction and motivation

The COVID-19 pandemic has had far-reaching economic repercussions. In the process, a new strand of economic literature has emerged, as academics strive to understand the impact of the pandemic on economic variables and to explore the relative merits of alternative economic policy responses.

However, explicitly modelling a pandemic in order to examine its impact on the economy is challenging, due to the large degree of uncertainty with respect to the nature, the persistence and the size of the shocks arising from it. Most of the relevant research argues that initially the pandemic prompts a labour supply shock, which then propagates throughout the economy. For example, Bayer et al. (2020) assume that a random fraction of workers is in quarantine, i.e. they have zero productivity, a state from which they probabilistically recover. Fornaro and Wolf (2020) choose to model the impact of the pandemic as a decline in labour productivity growth, leading to a long-lasting supply disruption. In the same vein, Guerrieri et al. (2020) assume that a fraction of agents are "unable" to supply any labour in the first period, as their occupation has been rendered unsafe, and then examine the economic outcomes in the second period. Conversely, Faria-e-Castro (2020) models the pandemic as a demand-side shock, i.e. a large negative shock to the marginal utility of consumption. A more innovative strand of this literature considers the economic implications of alternative containment policies by embedding an epidemiological model within otherwise standard Dynamic Stochastic General Equilibrium (DSGE) specifications. This renders the social distancing dynamics endogenous – see the seminal paper by Eichenbaum et al. (2020) as well as Glover et al. (2020), Jones et al. (2020), Krueger et al. (2020) and Velasco and Chang, (2020). However, the literature largely overlooks any interactions between the real and financial sectors when considering the economic effects of a pandemic.[1]

Our paper contributes to this literature by considering not only real, but also financial propagation mechanisms and their impact on the real economy and the banking sector. We are motivated by the extensive evidence on how the financial

[1] Faria-e-Castro (2020) explores the effects of the pandemic using a model that incorporates financial frictions. Our analysis differs since it incorporates endogenous collateral and bank default, as well as a corporate sector, allowing us to examine the interactions and feedback effects between the non-financial and the financial sectors.

accelerator amplifies adverse real shocks through worsening financial market conditions – see the seminal papers by Bernanke et al. (1996) and Kiyotaki and Moore (1997). These channels are also likely to come into play in the event of pandemic-induced economic shocks. Such a shock is introduced into a microfounded model with a rich financial sector, which allows us to trace the various real and financial transmission channels and gauge their relative importance at the short and medium horizon. The role of pandemic-driven increases in uncertainty and their impact on agents' loan repayment capacity and probability of default are also explored. Finally, we study the implications of increased financial sector instability and banks' own funding costs and we explore whether policy measures to support banking capital may have a mitigating effect. Our experiments provide a ranking of the policies employed to limit the economic impact of a pandemic, in terms of effectiveness.

To do so, we employ a version of the Dynamic Stochastic General Equilibrium (DSGE) model of Clerc et al. (2015), which has a detailed financial sector afflicted by multiple agency problems, including household, firm and bank default in equilibrium. It is thus suitable for examining the interactions between the real economy and the financial sector following the COVID-19 shock.

The model is calibrated to replicate key stylized facts of real and financial variables in Greece.[2] The experience of Greece makes an interesting case study. The first COVID-19 infection, confirmed on February 26, was a person who had just returned from Lombardy, the epicenter of the epidemic in Italy. In view of the devastating developments in the neighbouring country, and while in Greece the number of infections was very small and no deaths had yet been reported, the Greek government proceeded to impose drastic containment measures – in essence a full lockdown.[3] These measures are thought to be among the most proactive and strictest in Europe and have been credited for slowing down the spread of the disease and

[2] However, our findings are qualitatively robust to alternative calibrated values of key parameters and thus provide broader insights regarding the impact of the pandemic on advanced economies. Results for alternative calibrations are available upon request.

[3] Once fully unrolled, these included the closure of all educational institutions, cafes, bars, museums, shopping centers, sports facilities, restaurants and places of religious worship, coupled with the prohibition of all non-essential movement of civilians throughout the country. Starting from 4 May, after a 42-day lockdown, Greece began to gradually lift restrictions on movement, to restart business activity.

keeping the number of deaths among the lowest in Europe (see *inter alia* OECD, 2020, and Giugliano, 2020).[4] This undoubtedly successful pandemic containment policy came at a substantial economic cost, which is still unfolding. Given Greece's very low incidence of infections and deaths, this economic cost stems not from the disease's morbidity and mortality rates, but rather from the lockdown and from the impact that fear of contagion may have had on economic agents' decisions. It is precisely these drivers that we try to capture through the various shocks we introduce into the model.

In line with the aforementioned literature, we model the pandemic by introducing an adverse labour supply shock that works not only through real channels but also through financial channels to generate an economic downturn. We take care to calibrate the size of the shock so as to match the official estimate of the share of employment affected by the lockdown. In order to explore the effects of the heightened uncertainty surrounding economic and financial activity during the pandemic, we augment our analysis along two dimensions: first, we investigate the effects of higher risk for households and entrepreneurs, and, second, we explore the implications of a rise in the level of financial distress. To accurately quantify the increase in risk, we generate GARCH estimates of the change in the conditional variance of the appropriate FTSE indices following the outbreak of the pandemic and calibrate the risk shocks accordingly.

We find that the negative labour supply shock can have sizable implications for the real economy, which are further propagated through the reduction in banking capital and the increase in the funding cost of banks, generating an adverse effect on the supply of loans. The pandemic-induced increase in financial uncertainty also has real effects, including high and protracted firm bankruptcies and a more fragile banking sector, thus hindering the financing of the real economy. The results also indicate that the duration of the pandemic matters for its impact on the macroeconomy, as both business investment and bank balance sheets take disproportionately longer to recover.

[4] See for example https://www.bloomberg.com/opinion/articles/2020-04-10/greece-handled-coronavirus-crisis-better-than-italy-and-spain

Our findings underline the need for well-targeted policy measures to support the real economy and, secondarily, the financial sector during the pandemic and provide justification for several of the policy initiatives recently taken by governments, central banks and regulatory institutions around the world. Moreover, we explore the importance of banking sector resilience and show that measures to mitigate the pandemic's adverse effects on banking capital can help contain the negative impact of the pandemic-related risk shocks on the financial sector and the real economy. However, we find that measures to safeguard the financial system during the pandemic offer smaller gains than real economic policies, the latter being of paramount importance.

The remainder of the paper is structured as follows. In Section 2 we present the main ingredients of the model and discuss the elements we introduce in order to study the economic impact of the pandemic. In Section 3 we discuss the calibration of the model. Section 4 presents the dynamic effects of the pandemic on the economy and Section 5 explores the role of financial risk. In Section 6 we explore whether safeguarding banking capital can mitigate the adverse effects of the pandemic-driven increase in financial risk. We also conduct a counterfactual experiment, in which the banking system is assumed perfectly safe, to explore the role of banks' own funding cost risk. Section 7 provides some policy implications and concluding remarks.

2. The model economy

The model is based on Clerc et al. (2015) and is augmented to include a labour disutility shock and a shock to banking capital. In this model economy, households supply labour in a competitive market and save in the form of housing investment and deposits. They borrow from banks using their housing as collateral and default on their loans when the value of their housing is less than the debt payments. Entrepreneurs own the physical capital and they finance new purchases of capital with corporate loans. They default when the gross returns from capital investment cannot cover their debt obligations. Banks specialise in either mortgage or corporate loans and their funding is composed of deposits from households and inside equity from bankers. Banks default when the returns on their loan portfolio cannot fully pay the depositors. Thus, the interest rate on deposits includes a risk premium, to compensate for the banks' default risk. All borrowers (households, entrepreneurs and banks) are subject to idiosyncratic shocks that affect the value of their assets and thus their repayment capacity. Below, we discuss how we modify the model to study the economic impact of the pandemic. The formal model is described in the Appendix.

2.1. Introducing the COVID-19 shock into the model

As regards the pandemic shock, most of the related literature typically introduces a negative shock to labour supply or labour productivity (see for example Bayer et al., 2020, Fornaro et al., 2020 and Guerrieri et al., 2020). We adopt a similar perspective and model the pandemic as a temporary positive shock to the marginal disutility of labour, which generates an adverse effect on labour supply. In particular, using the Clerc et al. (2015) notation, the lifetime utility function of household j is written as:

$$E_t\left[\sum_{i=0}^{\infty}(\beta^j)^{t+i}[\log(c_{t+i}^j) + v^j\log(h_{t+i-1}^j) - \frac{\varphi^j}{1+\eta}\zeta_{t+i}(l_{t+i}^j)^{1+\eta}]\right] \quad (1)$$

where c_t^j denotes consumption, h_t^j denotes the total stock of housing, l_t^j denotes hours worked, η is the inverse of the Frisch elasticity of labour supply and v^j and φ^j are preference parameters. ζ_t is the preference shock we introduce, which affects the intertemporal decision for labour supply. It follows an $AR(1)$ process of the form: $\log(\zeta_t) = \rho_\zeta \log(\zeta_{t-1}) + \varepsilon_{\zeta,t}$, $\varepsilon_{\zeta,t} \sim_{i.i.d} N\left(0, \sigma_{\varepsilon_\zeta}\right)$, where ρ_ζ is the persistence parameter. An increase in ζ_t weakens households' incentives to engage in labour market activities, thereby producing an adverse effect on labour supply.

Our modelling choice is motivated by the fact that the first-order effect of the outbreak of the epidemic is on labour supply, as: i) individuals infected by the virus are not able to work; and ii) the containment measures aimed at reducing social interactions will result in a temporary decrease in labour supply. The shock specification we adopt aims to mimic both voluntary social distancing in the workplace and the state-imposed lockdown. As we shall see below, its effects permeate the economy through both real and financial channels.

Additionally, we gauge the effects of the heightened uncertainty surrounding economic and financial activity during the pandemic. To do so we augment our analysis along two dimensions. First, we investigate the effects of higher risk for households and entrepreneurs, modelled as a temporary rise in the volatility of the idiosyncratic shocks that adversely affect the value of the housing and capital assets of households and entrepreneurs, respectively. Second, we explore the implications of a temporary increase in the level of bank distress. In this case, in addition to the risk shock to the non-financial sector, the economy also suffers an idiosyncratic bank risk shock which reduces the performance of the loan portfolio of banks and worsens their balance sheets. All four risk shocks, namely the risk shocks to households, entrepreneurs, mortgage banks and corporate banks, follow an $AR(1)$ process of the form: $\log(s_t) = \rho_s \log(s_{t-1}) + \varepsilon_{s,t}$, $\varepsilon_{s,t} \sim_{i.i.d} N(0, \sigma_s)$, where $s = \{\tilde{\sigma}_m, \tilde{\sigma}_e, \tilde{\sigma}_H, \tilde{\sigma}_F\}$, are respectively the risk shocks to households, entrepreneurs, mortgage banks and corporate banks and ρ_s is the persistence parameter.

3. Calibration of the model

The model is calibrated to the Greek economy at a quarterly frequency to match key features of the Greek data. The calibration is based on the work of Balfoussia et al. (2019) and the calibration procedure closely follows the approach in Mendicino et al. (2018). The calibrated parameters and the long-run solution are summarized in Tables A1-A2 in the Appendix.

The key challenge in this analysis is to correctly calibrate the size of the labour supply shock. We calibrate it so as to reduce hours worked by 25.4% on impact, i.e. to match the official estimate of the share of employment affected by the lockdown.[5] This estimate should be viewed as a lower bound on the employment effect of the lockdown, as it includes employment in all the sectors which were compulsorily locked down. To the extent that other sectors voluntarily curtailed their activities during the lockdown or employees voluntarily abstained from work, the actual impact will have been larger.

In order to calibrate the size of the risk shocks to households and entrepreneurs, $\tilde{\sigma}_m, \tilde{\sigma}_e$, we adopt a different approach: we employ a $GARCH$ model to estimate the change in the conditional variance of composite FTSE indices for Greek non-financial corporations following the outbreak of the pandemic. More specifically, we use a $GARCH\,(1{,}1)$ model on daily composite FTSE indices for Greek non-financial corporations and estimate the conditional variance over the period 2 January 2018-15 May 2020. We then compute the average value of the conditional variance for the period from February 26, when the first confirmed coronavirus case was announced in Greece, to March 31, one week after the announcement of the full lockdown. We compute the size of the risk shock as the difference in the average value of the conditional variance over that period, relative to the average value of the conditional variance over the preceding six months. The results suggest a rise in risk by 3.8 standard deviations. We assume that this shock is common to households and entrepreneurs.

To calibrate the size of the risk shocks to the banking sector, $\tilde{\sigma}_H, \tilde{\sigma}_F$, we follow the same approach, using a composite FTSE index for Greek banks. Bank risk is estimated to have increased by 3.4 standard deviations, following the outbreak of the pandemic.

Finally, an important determinant of the economic impact of the pandemic will be the persistence of these shocks. This will ultimately depend on the duration of the

[5] See Hellenic Statistical Authority (2020).

outbreak, which is currently uncertain. We thus consider two alternative scenarios: i) the "baseline scenario" in which the half-life of the shock is one quarter and ii) the "adverse scenario" in which its half-life is two quarters. This is achieved by setting the persistence parameters equal to 0.5 and 0.7 in the baseline and adverse scenarios, respectively, in line with the relevant literature, which generally assumes pandemic-related shocks are relatively short-lived.

4. The dynamic effects of a pandemic on the economy

Figures 1 and 2 show the dynamic responses of key real and financial variables following the adverse labour supply shock that reduces hours worked by 25.4% on impact. Table 1 summarizes the quantitative results from the impulse responses.

[Figures 1 and 2 about here]

Turning first to Figure 1, in the baseline scenario the shock generates a reduction in labour supply which leads to a reduction in output. The marginal productivity of capital declines and so does business investment. At the same time, the lower labour income triggers a negative income effect, inducing households to reduce their consumption and housing investment. This, in turn, further dampens aggregate demand and output. The decline in the price of capital and housing further reduces the value of physical capital and housing. Within the model, these assets are respectively used by entrepreneurs and households as collateral when securing bank credit. Consequently, the financial position of both households and entrepreneurs worsens, prompting a rise in the rate of default on both mortgages and business loans.

Figure 2 illustrates how the real economy interacts with the banking sector. There are two channels which jointly affect the supply of loans and thus the financing of the real economy. Specifically, the increase in the default rates of households and entrepreneurs adversely affects the value of the banks' loan portfolio and capital, placing downward pressure on the supply of loans (bank capital channel). At the same time, the lower return on the loan portfolio raises banks' own default risk. This leads to an increase in the risk premium demanded by depositors in order for them to entrust their funds to the risky banks, i.e. an increase in the banks' cost of deposit funding. As a result, the lending rates for mortgages and business loans also increase (bank funding channel). Both channels adversely affect the financing of the real economy and thus prompt a further reduction in the price of collateral and a second-round increase in borrower default rates, setting a vicious circle in motion.

As summarized in Table 1, output, business investment, banking capital and total credit decrease on average by 6.65%, 10.35%, 0.49% and 0.44%, respectively, over the first four quarters, in the baseline scenario. However, the pandemic takes its greatest toll on financial variables in quarters 5-8, as the hump-shaped response of the default rates and the deposit risk premium induces a protracted decline in banking capital and total credit, which reaches 2.41% and 0.98%, respectively, in that period.

As a result, the duration of the financial cycle is much longer than that of the business cycle, in line with recent empirical evidence.[6]

[Table 1 about here]

Our results so far assumed that the pandemic shock is short lived with a half-life of one quarter. In the adverse scenario (half-life of two quarters), where the initial decline in labour supply is the same but its rebound is slower, the economic downturn is deeper and longer lasting. Output and business investment decrease respectively by about 9.3% and 17% on average over the first four quarters. Thus, every one-quarter extension of the shock's half-life results in an additional output loss of around 2.6%. The higher persistence of the shock especially affects banking capital which declines by more than 5%, causing protracted second-round effects.

5. The role of financial risk

The pandemic has also spurred a sharp increase in financial risk, prompting concerns about the financial positions of households and corporations and the stability of the financial system (e.g. Baker et al., 2020). To account for this, we first examine the effects of a risk shock to households and entrepreneurs that experience a common increase in risk by 3.8 standard deviations. Second, we investigate the importance of the level of financial distress as captured by a rise in the volatility of idiosyncratic shocks to banks, that is, an increase in risk for both types of banks by 3.4 standard deviations.

[Figures 3 and 4 about here]

Figures 3 and 4 and Table 2 present the economy's dynamic response to the financial risk shocks.[7] The risk shock to the non-financial sector directly reduces the price of the assets which households and entrepreneurs pledge as collateral in order to obtain bank loans. On impact, there is a sharp reduction of housing and business investment and, thus, of GDP. The prices of both housing and physical capital further decline, as does the loan repayment capacity of the borrowers. Consequently, the risk of mortgage and corporate loan defaults rises, triggering a decline in the equity capital of banks. The implications of this decline are twofold: first, total credit shrinks, generating a negative second order feedback effect on GDP; second, the risk of bank default increases, pushing up the cost of deposit funding. Eventually, as Table 2 shows, there is a reduction in output, business investment and banking capital by 0.67%, 3.56% and 2.98%, respectively, over the first four quarters. The effects are magnified in the adverse scenario, in which the fall in business investment is more than double compared to the baseline scenario.

[6] For a review of this literature see, among others, Rünstler et al. (2018).
[7] For brevity, we only report results for the baseline scenario. Results for the adverse scenario are available upon request.

Notably, when considering the aforementioned shocks in combination, their adverse aggregate effect on the corporate sector is substantial and protracted, as revealed when one considers *inter alia* the aggregate rate of entrepreneurial default. This finding echoes a major concern voiced in relation to the pandemic's economic impact, namely the potentially long-lasting and detrimental consequences of snowballing firm closures – see, for example, Guerrieri et al. (2020) who model and discuss the notion of a firm bankruptcy multiplier within an economic model of the pandemic.

[Table 2 about here]

When, in addition to the risk shock to the non-financial sector, the economy is hit by a rise in bank risk (the 'high financial distress' case in Table 2), banking capital declines further and bank funding cost rises, prompting a larger reduction in total credit and, thus, in output. The bank risk increase has more muted real effects than the risk shock to the non-financial sector, although it leads to a temporarily higher risk of bank default. This reflects the fact that the non-financial private sector is inherently riskier than the banking sector, which pools private risk. It follows that protecting the balance sheets of households and firms during a pandemic-driven downturn is pivotal to maintaining both macroeconomic and financial stability.

6. The relative importance of the financial sector

6.1. Safeguarding banking capital

A number of papers study the economic benefits of alternative fiscal policy measures (see Bayer, 2020, and Fornaro and Wolf, 2020, *inter alia*) during a pandemic. As our focus is on the role of real and financial sector linkages during the pandemic, we explore whether there is scope for including macroprudential measures which foster financial stability, as part of the policy toolbox used to contain the economic impact of the pandemic. Policy makers are not able to alleviate the forms of uncertainty described in the previous section, especially during the early stages of the outbreak. However, they do take measures to limit their adverse effects on the financial sector and thus on the real economy, primarily by safeguarding banking capital, i.e. by ensuring the resilience of the banking sector. For example, most supervisory authorities have imposed some form of restrictions on banks' capital distribution during the Covid-19 pandemic, in an effort to ensure that they maintain sufficient resources to support the real economy (see for example Svoronos and Vrbaski, 2020).[8] In order to explore the effects of such supervisory measures, in

[8] Such restrictions complement the relaxation of capital requirements, as they induce banks to devote their resources to absorbing losses and maintaining lending levels. Moreover, they arguably contribute to a more socially acceptable sharing of the overall costs of the pandemic. Svoronos and Vrbaski (2020) go so far as to argue that "blanket" distribution restrictions (i.e. restrictions imposed on all

tandem with the aforementioned risk shocks to households, entrepreneurs and banks, we introduce a positive shock to the net worth of bankers, calibrated so as to exactly cancel out the adverse effect of the risk shocks on banking capital in the impact period. This positive shock can be thought of as representing the potential cumulative effect of any combination of measures the supervisory authorities may adopt to safeguard banking capital, including *inter alia* dividend payment restrictions, stock buyback prohibitions and indirect or direct capital injections.

Specifically, the net worth of bankers is written as:

$$W_{t+1}^{b} = \zeta_t^{w}\left(\tilde{\rho}_{t+1}^{F} e_t^{F} + \tilde{\rho}_{t+1}^{H}\left(n_t^{b} - e_t^{F}\right)\right) \tag{2}$$

where $\tilde{\rho}_{t+1}^{F}, \tilde{\rho}_{t+1}^{H}$ are the ex post gross returns on the inside equity invested in the banks that specialize in entrepreneurial loans (F banks) and the banks that specialize in mortgage loans (H banks), e_t^{F} is the amount of the initial wealth, n_t^{b}, invested as inside equity in F banks and the rest, $n_t^{b} - e_t^{F}$, in H banks (for further details about the model structure of the banking sector, see the Appendix). ζ_t^{w} is a shock that affects the bankers' wealth. A rise in ζ_t^{w} increases the available amount that can be allocated to inside equity capital, putting downward pressures on the rate of return of bank equity and thus on lending rates. It follows an $AR(1)$ process, $\log(\zeta_t^{w}) = \rho_{\zeta^w}\log(\zeta_{t-1}^{w}) + \varepsilon_{\zeta^w,t}$, $\varepsilon_{\zeta,t} \sim_{i.i.d} N\left(0, \sigma_{\varepsilon_{\zeta^w}}\right)$, where ρ_{ζ^w} is the persistence parameter.

As seen in Figures 5 and 6, measures to mitigate the pandemic's adverse effects on banking capital help contain the negative effects of the pandemic-related risk shocks on the financial sector and the real economy, especially in the short run. In particular, the trajectory of lending rates is substantially improved, leading to a much smaller decline in total credit. As a result, business investment also declines by less and so does GDP.[9,10]

[Figures 5 and 6 about here]

financial institutions irrespective of their individual capital positions) are preferable, as they remove any possible stigma effect.

[9] We report results for the baseline scenario in which the half-life of the shocks is one quarter (the persistent parameter is set at 0.5). Results for the adverse scenario are available upon request.

[10] We have also considered the case where capital requirements react strongly countercyclically to deviations of total credit from its steady state value – i.e. in appendix equation (B32) we set $\bar{\phi}_1^{j}$ equal to 0.5. By doing so, we introduce a sensitive countercyclical capital buffer into the model. We study the effects of the various shocks in this specification and find that, as expected, the countercyclical adjustment alleviates the negative effects on output in the very short run, by supporting total credit. However, over the medium term, bank defaults rise exerting a negative effect on bank funding cost and thus eventually amplifying the negative effects of the pandemic shocks on output. Results are available upon request.

6.2. Banking sector risk – a counterfactual experiment

The above results notwithstanding, from the policy maker's perspective it is important to gauge the relative importance of the various transmission channels, in order to select the policy mix that would most effectively tackle the economic effects of a pandemic. In other words, it would be useful to be able to rank policy measures in terms of their impact vis-à-vis a pandemic-induced economic shock. To do so, we examine the effects of the labour supply shock under a counterfactual scenario, in which banks are not subject to idiosyncratic risk and thus there is no bank default in equilibrium. In this case, the funding cost channel is switched off and only the banking capital channel is at work. The latter channel is the stronger of the two, *albeit* weakened in this case due to smaller second round effects. However, our aim here is to isolate the role of uncertainty on the liabilities' side of the bank balance sheet, i.e. the importance of the banking system's credit-worthiness during a pandemic. Note that not all financial frictions are switched off – financial frictions in the non-financial private sector are still present – but banking sector frictions stemming from the liabilities' side are entirely cancelled. In other words, bank deposits are now perfectly safe and thus the deposit spread is zero, rendering deposit funding costless for the banking sector.

Table 3 compares the impact of the labour supply shock under the full model to that obtained under the counterfactual scenario, in which there is no bank default (for the counterfactual case, see the numbers in brackets).[11] The results illustrate that the contribution of the bank funding risk channel to the pandemic's overall economic impact is relatively small. The labour supply shock's adverse effect on banking capital and total credit under the counterfactual scenario is markedly smaller, but GDP and investment decline by only marginally less. Viewed in conjunction with the results presented in earlier sections, these findings imply that the bulk of the labour supply shock's economic impact comes through real transmission channels and through the balance sheets of the private non-financial sector. Banking capital and banking sector risk are also important, but relatively less so.

[Table 3 about here]

7. Policy implications and conclusions

Our findings have a number of policy implications for the containment of pandemic-induced economic downturns. First, measures designed to preserve jobs and support employment during the pandemic would decrease the duration of the negative labour supply shock and, thus, limit its adverse effects on both real economic activity and financial stability. Second, supporting the private non-financial sector's loan repayment capacity is key to protecting banks' balance sheets, banking capital

[11] The corresponding results for the effects of the risk shock in the non-financial sector (i.e. households and entrepreneurs) under the counterfactual scenario of no bank default are also available upon request.

and thus the financing of the real economy both during and after the pandemic. Finally, curbing bank funding costs and banking risk, as well as steering banks towards using more of their capital to finance economic activity, can help contain the negative effects of the pandemic on the financial sector and reduce the feedback effects from the financial sector to the real economy. In sum, our findings provide justification for several of the policy initiatives recently taken by governments, central banks and regulatory institutions around the world, such as the various job protection schemes (e.g. the US Paycheck Protection Program and the UK Coronavirus Job Retention Scheme) and measures to ensure adequate funding for banks at very low rates and to provide temporary capital relief to US and euro area banks.[12]

Moreover, they allow us to create a pecking order of the policies employed to limit the economic impact of a pandemic: our findings suggest that real economic policies, designed to address the labour supply shock itself, are paramount; underpinning the private non-financial sector's balance sheets should be the secondary policy aim; protecting the banking sector and limiting its riskiness is the third policy objective. This ranking could help policy makers prioritise their efforts, as it puts the various policy objectives in perspective. It is a reminder that, while financial stability is an important concern, pandemics such as the recent COVID-19 outbreak are, above all, real economic shocks which require real economic policy measures if they are to be effectively contained.

8. References

Baker, S. R., N. Bloom, S. J. Davis, K. Kost, M. Sammon, and T. Viratyosin, (2020), "The Unprecedented Stock Market Reaction to COVID-19", Becker Friedmand Institute W.P. No. 2020.

Balfoussia, H., H. Dellas, and D. Papageorgiou, (2019), "Fiscal distress and banking performance: the role of macroprudential regulation", CEPR Discussion Paper DP14003.

Bayer, C., B. Born, R. Luetticke and G. Müller, (2020), "The coronavirus stimulus package: How large is the transfer multiplier?", CEPR Discussion Paper 14600.

Bernanke, B., M. Gertler and S. Gilchrist, (1996), "The Financial Accelerator and the Flight to Quality", Review of Economics and Statistics. 78 (1): 1–15.

Clerc, L, A. Derviz, C. Mendicino, S. Moyen, K. Nikolov, L. Stracca, J. Suarez and A. P. Vardoulakis, (2015), "Capital regulation in a macroeconomic model with three layers of default", International Journal of Central Banking, 11, 3, 9–63.

Eichenbaum, M., S. Rebelo and M. Trabandt, (2020), "The macroeconomics of epidemics", CEPR DP14520.

[12] See www.bankingsupervision.europa.eu/press/pr/date/2020/html/ssm.pr200312~43351ac3ac.en.html and www.federalreserve.gov/supervisory-regulatory-action-response-covid-19.htm.

Faria-e-Castro, M. (2020), "Fiscal policy during a pandemic", Federal Reserve Bank of St. Louis

Working Paper No. WP 2020-006A.

Fornaro, L. and M. Wolf, (2020), "Covid-19 Coronavirus and Macroeconomic Policy" CEPR DP14529.

Giugliano, F., (10 April 2020). "Greece Shows How to Handle the Crisis", Bloomberg, available at https://www.bloomberg.com/opinion/articles/2020-04-10/greece-handled-coronavirus-crisis-better-than-italy-and-spain.

Glover, Andrew, Jonathan Heathcote, Dirk Krueger and Jose-Victor Rios-Rull, (2020), "Health versus wealth: on the distributional effects of controlling a pandemic", CEPR Discussion Paper 14606.

Guerrieri, Veronica, Guido Lorenzoni, Ludwig Straub and Iván Werning, (2020), "Macroeconomic implications of COVID-19: Can negative supply shocks cause demand shortages?", NBER Working Paper 26918.

Hellenic Statistical Authority (2020), "Statistical data on enterprises under suspension of operation due to the pandemic of corona virus disease 2019 (COVID-19)", Press Release, 16 April 2020.

Jones, Callum J., T. Philippon and V. Venkateswaran, (2020), "Optimal mitigation policies in a pandemic: social distancing and working from home", NBER W.P. 26984.

Kiyotaki, N. and J. Moore, (1997), "Credit Cycles". Journal of Political Economy. 105 (2): 211–248.

Krueger, D., H. Uhlig and T. Xie, (2020), "Macroeconomic dynamics and reallocation in an epidemic", CEPR Discussion Paper 14607.

Mendicino C., K. Nikolov, J. Suarez and D. Supera, (2018), "Optimal Dynamic Capital Requirements", Journal of Money, Credit and Banking, Blackwell Publishing, 50, 6, 1271-1297.

OECD (2020), OECD Economic Surveys: Greece 2020, OECD Publishing, Paris,

https://doi.org/10.1787/b04b25de-en.

Rünstler, G., H. Balfoussia, L. Burlon, G. Buss, M. Comunale, B. De Backer, H. Dewachter, P. Guarda, M. Haavio, I. Hindrayanto, N. Iskrev, I. Jaccard, D. Kulikov, D. Kunovac, Č. Lenarčič, M. Lequien, M. Lozej, M. Mandler, D. Papageorgiou, J. Pedersen, G. Perez-Quiros, A. Rannenberg, E. Rots, M. Scharnagl and P. Welz, (2018), "Real and financial cycles in EU countries: Stylised facts and modelling implications", ECB Occasional Paper No. 205.

Svoronos, J.P. and R. Vrbaski, (2020), "Banks' dividends in Covid-19 times", FSI Briefs No 6, BIS.

Velasco, A., and R. Chang, (2020), "Economic policy incentives to preserve lives and livelihoods", CEPR Discussion Paper 14614.

9. Figures and tables

Figure 1: Dynamic effects of a labour disutility shock on the real economy

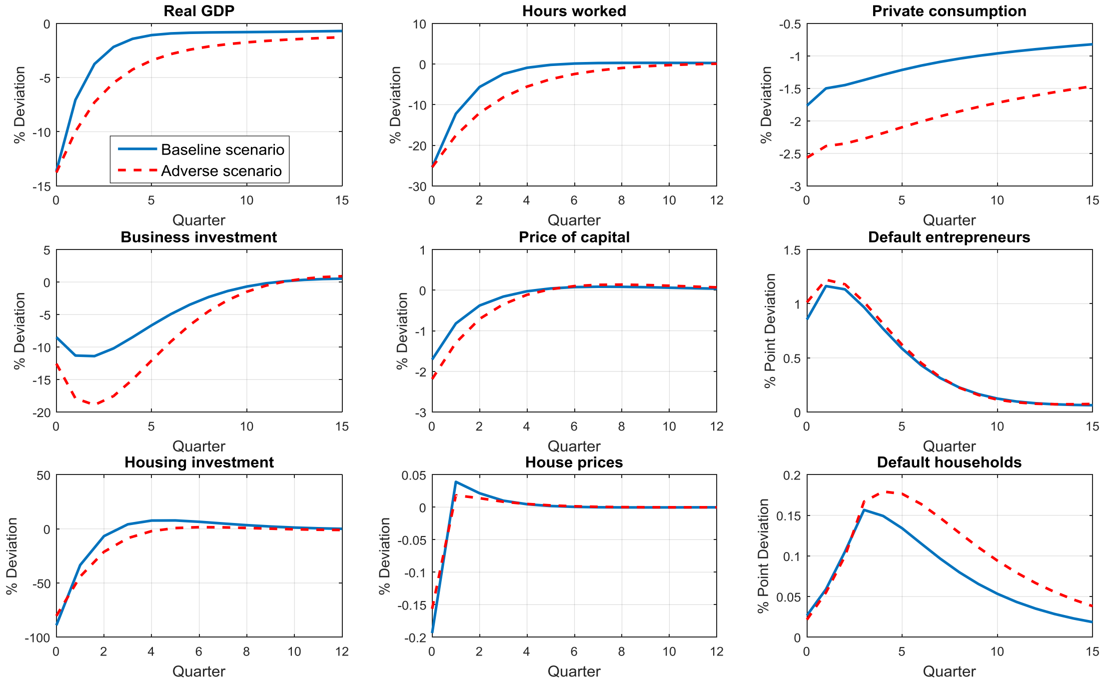
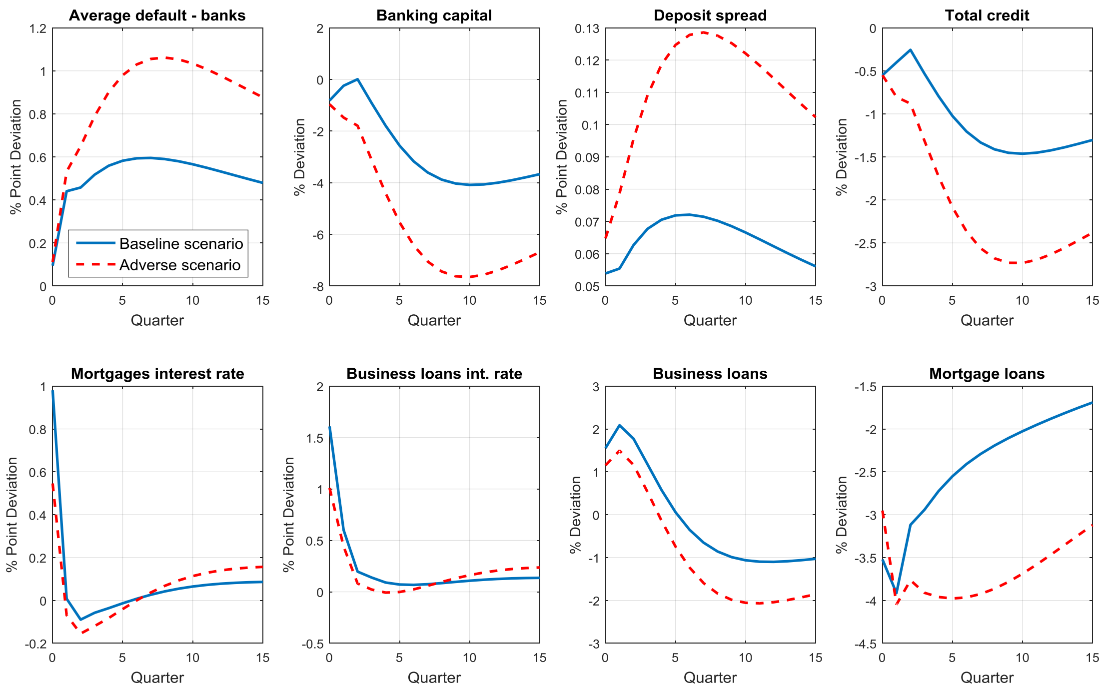


Figure 2: Dynamic effects of a labour disutility shock on the banking sector



Notes to Figures 1 and 2: i) All variables are expressed in percentage deviations from the steady state, with the exception of the default rates, the deposit spread and the interest rates that are expressed as percentage point deviations (annualized), ii) "Benchmark scenario": the half-life of the shock is 1 quarter, "High persistence": the half-life of the shock is 2 quarters, iii) The size of the shock is calibrated to reduce hours worked by 25.4% on impact.

Figure 3: Dynamic effects of risk shocks on the real economy

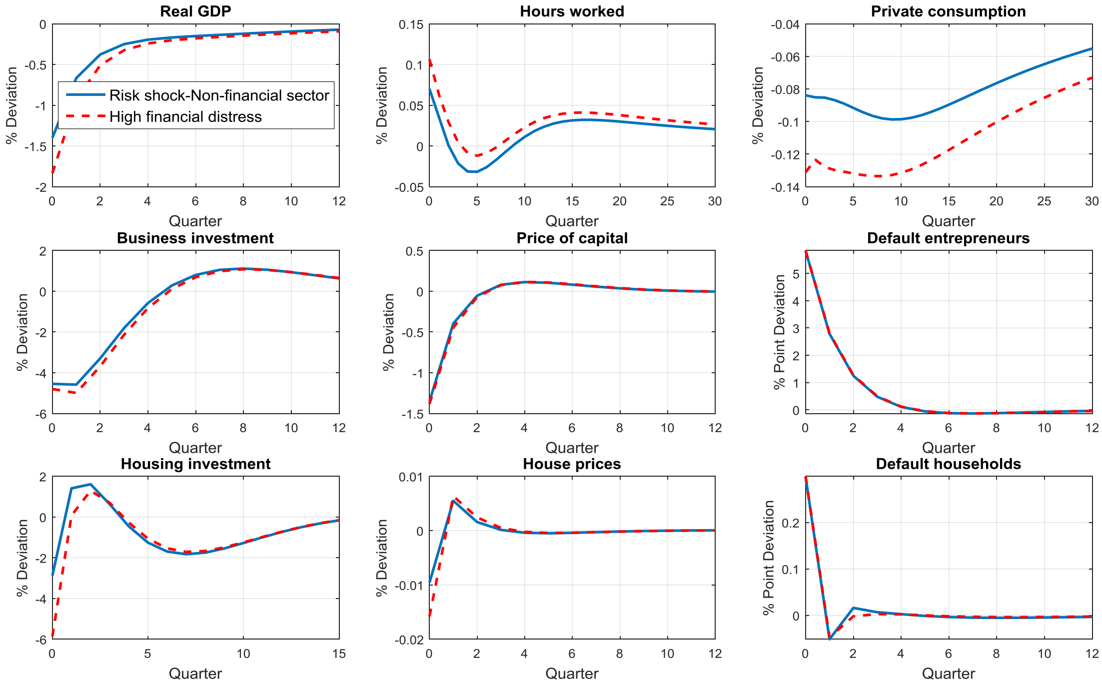
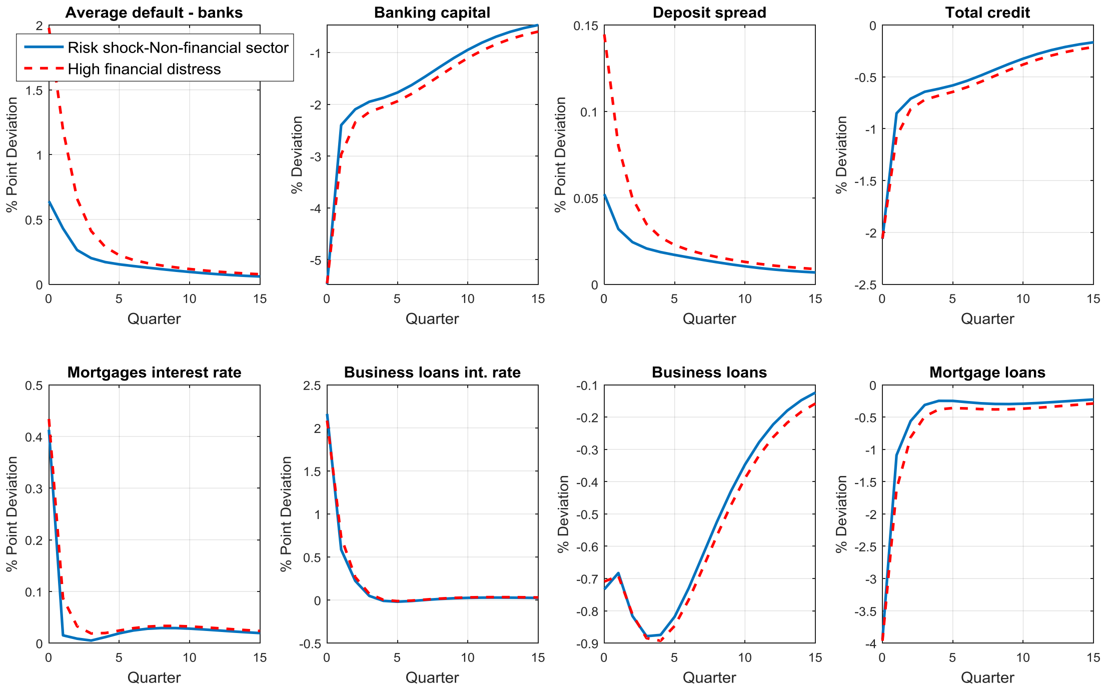


Figure 4: Dynamic effects of risk shocks on the banking sector



Notes to Figures 3 and 4: i) All variables are expressed in percentage deviations from the steady state, with the exception of the default rates, the deposit spread and the interest rates that are expressed as percentage point deviations (annualized), ii) The variance of the idiosyncratic shocks to households and entrepreneurs is increased by 3.8 standard deviations on impact, iii) Under high financial distress, the economy is hit by risk shocks both in the non-financial and the banking sectors. The variance of the idiosyncratic shocks to the banking sector is increased by 3.4 standard deviations on impact, iv) Results reported are for the baseline scenario in which the half-life of shocks is one quarter.

Figure 5: Financial distress accommodated by banking capital support (real economy)

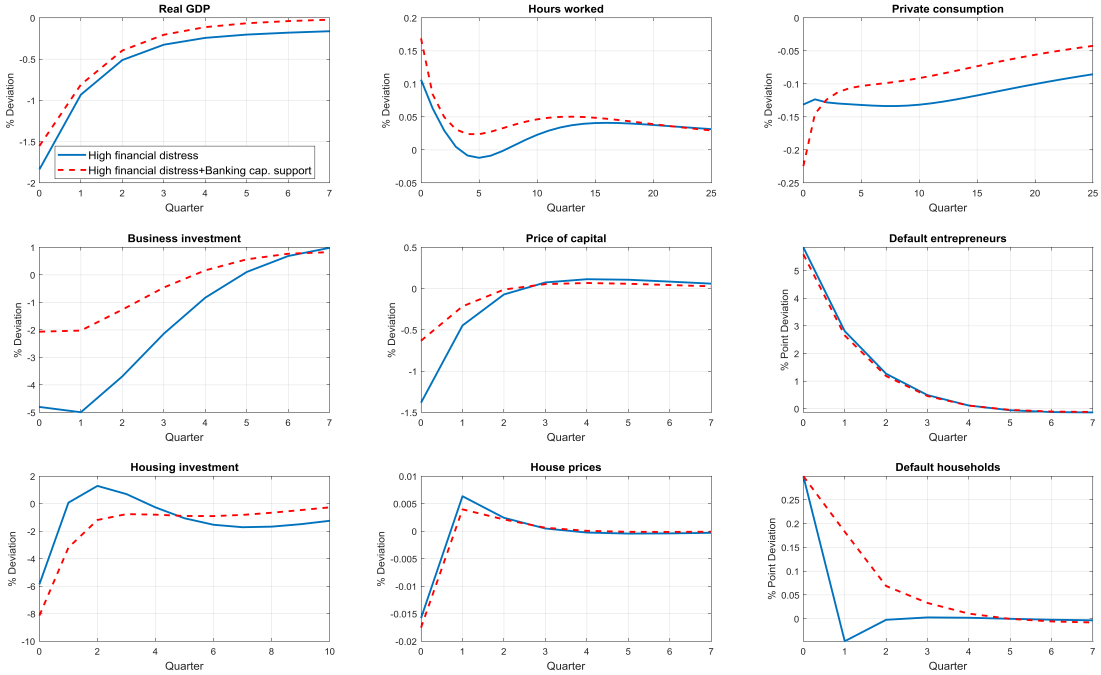
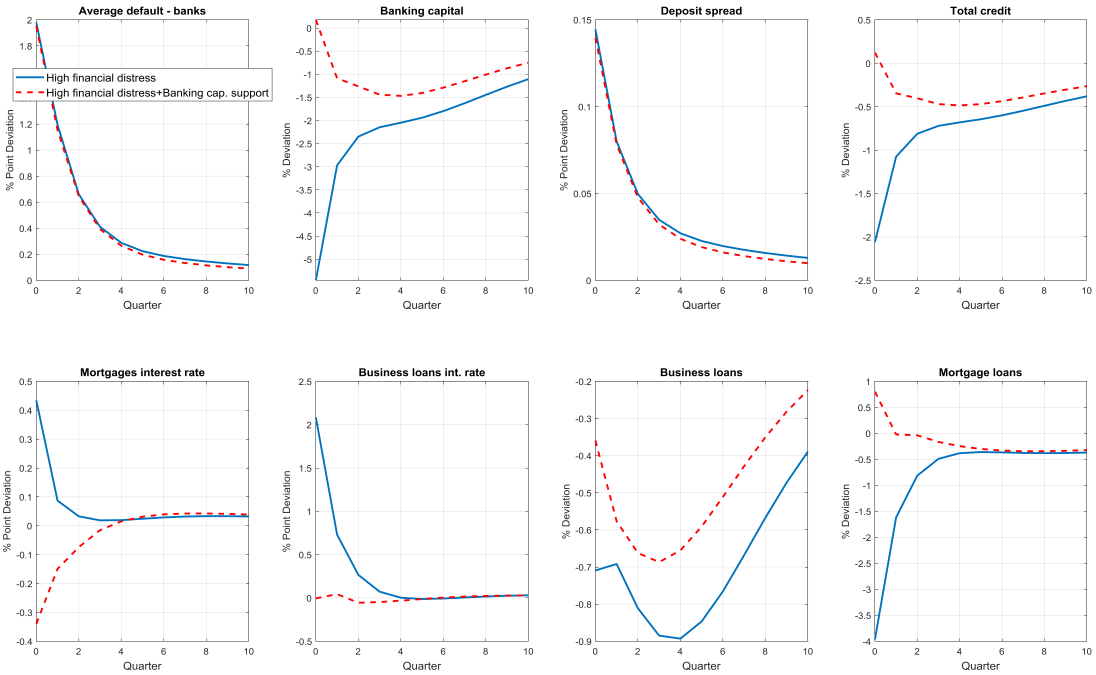


Figure 6: Financial distress accommodated by banking capital support (banking sector)



Notes to Figures 5 and 6: i) All variables are expressed in percentage deviations from the steady state, with the exception of the default rates, the deposit spread and the interest rates that are expressed as percentage point deviations (annualized), ii) Under high financial distress, the economy is hit by risk shocks both in the non-financial and the banking sectors. The variance of the idiosyncratic shocks to households and entrepreneurs is increased by 3.8 standard deviations on impact. The variance of the idiosyncratic shocks to the banking sector is increased by 3.4 standard deviations on impact. The shock to the net worth of bankers is calibrated so that to cancel out the decrease in banking on impact period, iii) Results reported are for the baseline scenario in which the half-life of shocks is one quarter.

Table 1: Effects of a reduction in labour supply

Variable	Baseline scenario		Adverse scenario	
	Average over quarters 1-4	**Average over quarters 5-8**	**Average over quarters 1-4**	**Average over quarters 5-8**
Real GDP	-6.65	-1.07	-9.27	-3.74
Business investment	-10.35	-6.76	-17	-12.28
Hours worked	-11.43	-0.64	-16.05	-4.37
Private consumption	-1.52	-1.22	-2.43	-2.12
Banking capital	-0.49	-2.41	-1.87	-5.39
Total credit	-0.44	-0.98	-0.9	-2.04
Default rate risk - Banks	0.38	0.57	0.53	0.97
Deposit spread	0.06	0.071	0.09	0.124
Default rate - Corporations	1.03	0.61	1.12	0.66
Default rate - Households	0.09	0.13	0.09	0.17

Note: i) All variables are expressed in percentage deviations relative to the pre-shocked steady state, except for the default rates that are expressed in percentage point changes (annualised), ii) "Baseline scenario": the half-life of the shock is 1 quarter, "Adverse scenario": the half-life of the shock is 2 quarters, iii) The size of the shock is calibrated to reduce hours worked by 25.4% on impact.

Table 2: Effects from an increase in risk

Variable	Baseline scenario		Adverse scenario	
	Average over quarters 1-4	**Average over quarters 5-8**	**Average over quarters 1-4**	**Average over quarters 5-8**
	Increase in the risk of households and entrepreneurs			
Real GDP	-0.67	-0.16	-1.00	-0.52
Business investment	-3.56	-0.05	-8.18	-1.41
Banking capital	-2.98	-1.74	-5.00	-5.20
Total credit	-1.07	-0.57	-1.71	-1.72
Default rate risk - Banks	0.38	0.16	0.58	0.46
Default rate - Corporations	2.59	0.05	3.46	0.42
Default rate - Households	0.07	0.00	0.11	0.02
	High financial distress			
Real GDP	-0.90	-0.20	-1.29	-0.62
Business investment	-3.90	-0.24	-8.69	-1.75
Banking capital	-3.23	-1.91	-5.41	-5.63
Total credit	-1.17	-0.64	-1.87	-1.85
Default rate risk - Banks	1.07	0.25	1.45	0.74
Default rate - Corporations	2.60	0.06	4.47	0.42
Default rate - Households	0.06	0.0	0.10	0.01

Note: i) All variables are expressed in percentage deviations relative to the pre-shocked steady state, except for the default rates that are expressed in percentage point changes (annualised), ii) "Baseline scenario": the half-life of the shock is 1 quarter, "Adverse scenario": the half-life of the shock is 2 quarters, iii) The variance of the idiosyncratic shocks to households and entrepreneurs is increased by 3.8 standard deviations on impact, iv) Under high financial distress, the economy is hit by risk shocks both in the non-financial and the banking sectors. The variance of the idiosyncratic shocks to the banking sector is increased by 3.4 standard deviations on impact.

Table 3: Effects of a reduction in labour supply (full model vs model without bank default)

Variable	Baseline scenario		Adverse scenario	
	Average over quarters 1-4	**Average over quarters 5-8**	**Average over quarters 1-4**	**Average over quarters 5-8**
Real GDP	-6.65 [-6.5]	-1.07 [-0.88]	-9.27 [-8.89]	-3.74 [-3.35]
Business investment	-10.35 [-9.92]	-6.76 [-6.2]	-17 [-16.06]	-12.28 [-11.13]
Hours worked	-11.43 [-11.48]	-0.64 [-0.69]	-16.05	-4.37
Private consumption	-1.52 [-1.44]	-1.22 [-1.13]	-2.43 [-2.26]	-2.12 [-1.94]
Banking capital	-0.49 [-0.33]	-2.41 [-2]	-1.87 [-1.56]	-5.39 [-4.59]
Total credit	-0.44 [-0.37]	-0.98 [-0.83]	-0.9 [-0.78]	-2.04 [-1.74]
Default rate risk - Banks	0.38 [0]	0.57 [0]	0.53 [0]	0.97 [0]
Deposit spread	0.06 [0]	0.071 [0]	0.09 [0]	0.124 [0]
Default rate - Corporations	1.03 [1.03]	0.61 [0.62]	1.12 [1.11]	0.66 [0.66]
Default rate - Households	0.09 [0.09]	0.13 [0.14]	0.09 [0.09]	0.17 [0.19]

Note: i) Numbers in brackets correspond to the case of no bank default, ii) All variables are expressed in percentage deviations relative to the pre-shocked steady state, except for the default rates that are expressed in percentage point changes (annualised), iii) “Baseline scenario”: the half-life of the shock is 1 quarter, “Adverse scenario”: the half-life of the shock is 2 quarters, iv) The size of the shock is calibrated to reduce hours worked by 25.4% on impact.

Appendix

A. Calibration and long-run solution

Table A1. Calibrated parameters

Description	**Parameter**	**Value**
Patient Household Discount Factor	β^s	0.992
Impatient Household Discount Factor	β^m	0.977
Patient Household Utility Weight of Housing	υ^m	0.25
Impatient Household Utility Weight of Housing	υ^s	0.25
Patient Household Marginal Disutility of Labor	φ^s	1
Impatient Household Marginal Disutility of Labor	φ^m	1
Inverse of Frisch Elasticity of Labor	η	1
Degree of Fiscal Frailty	γ	0.12
Household Bankruptcy Cost	μ^m	0.3
Entrepreneur Bankruptcy Cost	μ^e	0.3
Capital Requirement for Mortgage Loans	$\overline{\phi}^H$	0.04
Capital Requirement for Corporate Loans	$\overline{\phi}^F$	0.08
Mortgage Bank Bankruptcy Cost	μ^H	0.3
Corporate Bank Bankruptcy Cost	μ^F	0.3
Capital Share in Production	α	0.4
Capital Depreciation Rate	δ	0.024
Housing Depreciation Rate	δ^H	0.0148
Housing Adjustment Cost Parameter	ξ^H	0.001
Capital Adjustment Cost Parameter	ξ^K	0.4
Dividend Payout of Bankers (Entrepreneurs)	$\chi^b(\chi^e)$	0.037
Std of Mortgage Bank Idiosyncratic Shock	σ_H	0.0163
Std of Corporate Bank Idiosyncratic Shock	σ_F	0.0331
Std of Household Idiosyncratic Shock	σ_m	0.157
Std of Entrepreneurial Idiosyncratic Shock	σ_e	0.49
Std of Risk Shock – Mortgage Banks	$\tilde{\sigma}_H$	0.0163
Std of Risk Shock – Corporate Banks	$\tilde{\sigma}_F$	0.0331
Std of Risk Shock – Households	$\tilde{\sigma}_m$	0.012
Std of Risk Shock – Entrepreneurs	$\tilde{\sigma}_e$	0.035
Persistence Parameter – Benchmark scenario	ρ^b	0.5
Persistence Parameter – Adverse scenario	ρ^a	0.7071

Table A2. Long-run solution

Description	Data averages	Long run solution
Total consumption over GDP	0.64	0.596
Investment (related to the capital good production)/over GDP	0.147	0.147
Investment in housing/over GDP	0.084	0.088
The premium required by depositors in order to deposit their money in the risky bank	0.231	0.246
Debt-to-GDP ratio of entrepreneurs (annualized)	0.491	0.489
Debt-to-GDP ratio of borrowers (annualized)	0.421	0.338

B. The model

This section briefly presents the model of Clerc et al. (2015), extended to account for a labour disutility shock and a shock to the net worth of bankers.

Households

There are two representative dynasties of ex ante identical infinitely lived households that differ only in the subjective discount factor. One dynasty, indexed by the superscript s, is made up of relatively patient households with a discount factor β^s. The other dynasty, identified by the superscript m, consists of more impatient households with a discount factor $\beta^m < \beta^s$. In equilibrium, the patient households save and the impatient households borrow from banks.

Saving Households

The dynasty of patient households maximizes

$$E_t\left[\sum_{i=0}^{\infty}(\beta^s)^{t+i}[\log(c_{t+i}^s) + v^s\log(h_{t+i-1}^s) - \zeta_{t+i}\frac{\varphi^s}{1+\eta}(l_{t+1}^s)^{1+\eta}]\right]$$
(B1)

subject to

$$c_t^s + q_t^H h_t^s + d_t \leq w_t l_t^s + q_t^H\left(1-\delta^H\right)h_{t-1}^s + \tilde{R}_t^D d_{t-1} - T_t + \Pi_t^s$$
(B2)

where c_t^s denotes the consumption of non-durable goods, h_t^s denotes the total stock of housing, l_t^s denotes hours worked, η is the inverse of the Frisch elasticity of labour supply, ζ_{t+i} is a preference shock and v^s and φ^s are preference parameters. Also, q_t^H is the price of housing, δ^H is the depreciation rate of housing units and w_t is the real wage rate. As owners of the firms, households receive profits, Π_t^s, that are distributed in the form of dividends. $\tilde{R}_t^D$, is defined as $\tilde{R}_t^D = R_{t-1}^D\left(1-\gamma PD_t^b\right)$, where R_t^D is the gross fixed interest rate on deposits in period t, PD_t^b is the economy-wide probability of bank default in period t and γ is the fraction of deposits that is not recovered when a bank defaults (the amount of depositor bail-in).

The presence of a deposit risk premium raises the funding cost for banks while, in addition, the fact that this premium depends on the economy-wide default risk rather than on their own default risk induces an incentive for banks to take excessive risk and provides a rationale for macroprudential policy.

Borrowing Households

Impatient households have the same preferences as patient households except for the discount factor, which is $\beta^m < \beta^s$:

$$E_t\left[\sum_{i=0}^{\infty}(\beta^m)^{t+i}[\log(c_{t+i}^m) + v^m\log(h_{t+i-1}^m) - \zeta_{t+i}\frac{\varphi^m}{1+\eta}(l_{t+1}^m)^{1+\eta}]\right] \tag{B3}$$

The budget constraint of the representative dynasty is:

$$c_t^m + q_t^H h_t^m - b_t^m \leq w_t l_t^m + \int_0^{\infty}\max\left\{\omega_t^m q_t^H\left(1-\delta^H\right)h_{t-1}^m - R_{t-1}^m b_{t-1}^m, 0\right\}dF^m(\omega_t^m) \tag{B4}$$

where b_t^m is aggregate borrowing from the banks and R_{t-1}^m is the contractual gross interest rate on the housing loan agreed upon in period $t-1$. ω_t^m is an idiosyncratic shock to the efficiency units of housing owned from period $t-1$ that each household experiences at the beginning of each period t. The shock is assumed to be independently and identically distributed across the impatient households and to follow a lognormal distribution with density and cumulative distributions functions denoted by $f(.)$ and $F(.)$, respectively. This shock affects the effective resale value of the housing units acquired in the previous period, $\tilde{q}_t^H = \omega_t^m q_t^H\left(1-\delta^H\right)$, and makes default on the loan *ex post* optimal for the household whenever $\omega_t^m q_t^H\left(1-\delta^H\right)h_{t-1}^m < R_{t-1}^m b_{t-1}^m$. The term in the integral reflects the fact that the housing good and the debt secured against it are assumed to be distributed across the individual households that constitute the dynasty.

After the realization of the shock, each household decides whether to default or not on its loans held from the previous period. Then, the dynasty makes the decisions for consumption, housing, labour supply and debt in period t and allocates them evenly across households. As shown in Clerc *et al*. (2015), individual households default in period t whenever the idiosyncratic shock ω_t^m satisfies:

$$\omega_t^m \leq \overline{\omega}_t^m = \frac{x_{t-1}^m}{R_t^H}$$
(B5)

where $R_t^H = \frac{q_t^H(1-\delta^H)}{q_{t-1}^H}$ is the ex post average realized return on housing and $x_t^m = \frac{R_t^m b_t^m}{q_t^H h_t^m}$ is a measure of household leverage. The net housing equity after accounting for repossessions of defaulting households can be written as:

$$\left(1-\Gamma^m(\overline{\omega}_t^m)\right)R_t^H q_{t-1}^H h_{t-1}^m,$$
(B6)

where $\Gamma^m(\overline{\omega}_t^m) = \int_0^{\overline{\omega}_{t+1}^m}(\omega_t^m f^m(\omega_t^m))d\omega_t^m + \overline{\omega}_{t+1}^m \int_{\overline{\omega}_1^m}^{\infty}(f^m(\omega_t^m))d\omega_t^m$ is the share of gross returns (gross of verification costs) accrued by the bank and $\left(1-\Gamma^m(\overline{\omega}_t^m)\right)$ is the share of assets accrued to the dynasty.

Since each of the impatient households can default on its loans, the loans taken in period t should satisfy the participation constraint for the lending banks:

$$E_t(1-\Gamma^H(\overline{\omega}_t^H))(\Gamma^m(\overline{\omega}_{t+1}^m) - \mu^m G^m(\omega_{t+1}^m))R_{t+1}^H q_t^H h_t^m \geq \rho_t \phi_t^H b_t^m \qquad \text{(B7)}$$

The left-hand side of the inequality accounts for the total equity returns associated with a portfolio of housing loans to the various members of the impatient dynasty. The interpretation of the banking participation constraint is that the expected gross return for bankers should be at least as high as the gross equity return of the funding of the loan from the bankers, $\rho_t \phi_t^H b_t^m$, where ρ_t is the required expected rate of return on equity from bankers (defined below) and ϕ_t^H is the capital requirement on housing loans. The term $\mu^m G^m(\omega_{t+1}^m)$ is the expected cost of default, where μ^m is the verification cost and $G^m(\omega_{t+1}^m) = \int_0^{\overline{\omega}_{t+1}^m}(\omega_{t+1}^m f(\omega_{t+1}^m))d\omega_{t+1}^m$ is the share of assets that belong to households that default. Finally, $(1-\Gamma^H(\overline{\omega}_t^H))$ is the share of assets accrued to bankers in the case of a bank default, where $\overline{\omega}_t^H$ is the threshold level to the idiosyncratic shock of banks that specialize in mortgage loans (defined below).

Given the above, the problem of the representative dynasty of the impatient households can be written compactly as a contracting problem between the representative dynasty and its bank. In particular, the problem of the dynasty is to maximize utility subject to the budget constraint and the participation constraint of the bank:

$$\max_{\{c^m_{t+1},\, h^m_{t+1},\, l^m_{t+1},\, x^m_{t+1},\, b^m_{t+1}\}^{\infty}_{i=0}} E_t \left[\sum_{i=0}^{\infty} (\beta^m)^{t+i} [\log(c^m_{t+i}) + \right.$$
$$+ v^m \log(h^m_{t+i})$$
$$\left. - \frac{\varphi^m}{1+\eta} (l^m_{t+1})^{1+\eta}] \right] \quad \text{(B8)}$$

subject to

$$c^m_t + q^H_t h^m_t - b^m_t \leq \omega_t l^m_t + \left(1 - \Gamma^m \left(\frac{x^m_t}{R^H_{t+1}}\right)\right) R^H_{t+1} q^H_t h^m_t$$
(B9)

and

$$E_t \left[(1 - \Gamma^H(\overline{\omega}^m_{t+1})) \left(\Gamma^m \left(\frac{x^m_t}{R^H_{t+1}}\right) - \mu^m G^m \left(\frac{x^m_t}{R^H_{t+1}}\right) \right) R^H_{t+1} \right] R^H_{t+1} q^H_t h^m_t = \rho_t \phi^H_t b^m_t$$

(B10)

Entrepreneurs

Entrepreneurs are risk neutral agents that live for two periods. Each generation of entrepreneurs inherits wealth in the form of bequests and purchases new capital from capital good producers and depreciated capital from the previous generation of entrepreneurs that they rent out to final good producers. They finance capital purchases with their initial wealth and with corporate loans from banks, b^e_t. The entrepreneurs derive utility from the transfers made to the patient households in period $t+1$ (dividends), c^e_{t+1}, and the bequests left to the next cohort of entrepreneurs (retained earnings), n^e_{t+1}, according to the utility function $(c^e_{t+1})^{\chi^e}(n^e_{t+1})^{1-\chi^e}$, $\chi^e \in (0,1)$. Thus, the problem of the entrepreneurs in period $t+1$ is:

$$\max_{\{c^e_{t+1}, n^e_{t+1}\}} (c^e_{t+1})^{\chi^e}(n^e_{t+1})^{1-\chi^e} \quad \text{(B11)}$$

subject to $c^e_{t+1} + n^e_{t+1} \leq W^e_{t+1}$, where W^e_{t+1} is the wealth resulting from the activity in the previous period. The optimization problem of the entrepreneur in period t is to maximize expected wealth:

$$\max_{\{k_t, b^e_t, R^F_t\}} E_t(W^e_{t+1}) \quad \text{(B12)}$$

subject to the period t resource constraint $q^K_t k_t - b^e_t = n^e_t$ and the bank's participation constraint (defined below), where $W^e_{t+1} = \max\{\omega^e_{t+1}(r^k_{t+1} +$

$(1-\delta\ \ )q_{t+1}^{K}\big)k_t - R_t^F b_t^e, 0\big\}$, q_t^K is the price of capital in period t, k_t is the capital held by the entrepreneur in period t, b_t^e is the amount borrowed from the bank in period t, r_t^k is the rental rate of capital, δ is the depreciation rate of physical capital and R_t^F is the contractual gross interest rate of the corporate loan. ω_{t+1}^e is an idiosyncratic shock to the efficiency units of capital which is independently and identically distributed across entrepreneurs. It is realized after the period t loan with the bank is agreed to and prior to renting the available capital to consumption good producers on that date. Similar to the case of borrowing households, entrepreneurs default on their loans whenever $\omega_{t+1}^e\big(r_{t+1}^k + (1-\delta\ \ )q_{t+1}^K\big)k_t < R_t^F b_t^e$. As shown in Clerc *et al.* (2015), the entrepreneur will repay their corporate loan in period $t+1$ whenever the indiosyncratic shock ω_{t+1}^e exceeds the following threshold:

$$\overline{\omega}_{t+1}^e \equiv \frac{R_t^F b_t^e}{R_{t+1}^K q_t^K k_t} \equiv \frac{x_t^e}{R_{t+1}^K}$$

(B13)

where $R_{t+1}^K = \frac{r_{t+1}^k + (1-\delta\ \ )q_{t+1}^K}{q_t^K}$ is the gross return per efficiency units of capital in period $t+1$ of capital owned in period t, $x_t^e = \frac{R_t^F b_t^e}{q_t^K k_t}$ denotes the entrepreneurial leverage that is defined as the ratio of contractual debt repayment obligations in period $t+1$, $R_t^F b_t^e$, to the value of the purchased capital at t, $q_t^K k_t$.

Given the above, the maximization problem of the entrepreneurs in period t can be compactly written as:

$$\max_{x_t^e, k_t} E_t\left[\left(1 - \Gamma^e\left(\frac{x_t^e}{R_{t+1}^K}\right)\right) R_{t+1}^K q_t^K k_t\right] \tag{B14}$$

subject to

$$E_t\big[(1-\Gamma^F(\overline{\omega}_{t+1}^F))\big(\Gamma^e(\overline{\omega}_{t+1}^e) - \mu^e G^e(\overline{\omega}_{t+1}^e)\big)\big]R_{t+1}^K q_t^K k_t = \rho_t \phi_t^F (q_t^K k_t - n_t^e) \tag{B15}$$

where $\Gamma^e(\overline{\omega}_{t+1}^e) = \int_0^{\overline{\omega}_{t+1}^e} (\omega_{t+1}^e f^e(\omega_{t+1}^e)) d\omega_{t+1}^e + \overline{\omega}_{t+1}^e \int_{\overline{\omega}_{t+1}^e}^{\infty} (f^e(\omega_{t+1}^e)) d\omega_{t+1}^e$ is the share of gross returns that will accrue to the bank, $G^e(\overline{\omega}_{t+1}^e) = \int_0^{\overline{\omega}_{t+1}^e} (\omega_{t+1}^e f^e(\omega_{t+1}^e)) d\omega_{t+1}^e$ is the fraction of the returns coming from the defaulted loans of entrepreneurs, μ^e denotes the verification costs incurred by the bank and $(1-\Gamma^F(\overline{\omega}_t^F))$ is the share of assets accrued to bankers in the case of a bank default, where $\overline{\omega}_t^F$ is the default threshold level for the idiosyncratic shock of banks that specialize in corporate loans (defined below). Similar to the case of impatient households, the interpretation of the participation constraint is that, in equilibrium, the expected return of the corporate loans must equal to the expected rate of return on equity, ρ_t, that the bankers require for their contribution to the funding of loan, $\phi_t^F(q_t^K k_t - n_t^e)$, where ϕ_t^F is the capital requirement applied on corporate loans.

Bankers

Like entrepreneurs, bankers are risk-neutral and live for two periods. They invest their initial wealth, inherited in the form of bequest from the previous generation of bankers, n_t^b, as bank's inside equity capital. In period $t+1$ the bankers derive utility from transfers to the patient households in the form of dividends, c_{t+1}^b, and the bequests left to the next generation of bankers (retained earnings), n_{t+1}^b, according to the utility function $\left(c_{t+1}^b\right)^{\chi^b}\left(n_{t+1}^b\right)^{1-\chi^b}$, where $\chi^b \in (0,1)$. Thus, the problem of the banker in period $t+1$ is:

$$\max_{\{c_{t+1}^b, n_{t+1}^b\}} \left(c_{t+1}^b\right)^{\chi^b}\left(n_{t+1}^b\right)^{1-\chi^b} \tag{B16}$$

subject to

$$c_{t+1}^b + n_{t+1}^b \leq W_{t+1}^b$$
(B17)

where W_{t+1}^b is the wealth of the banker in period $t+1$.

Regarding the decision problem of the bankers in period t, the banker born in period t with initial wealth n_t^b decides how much of this wealth to allocate as inside equity capital across the banks that specialize in housing loans (H banks) and the banks that specialize in entrepreneurial loans (F banks). Let e_t^F be the amount of the initial wealth n_t^b invested as inside equity in F banks and the rest, $n_t^b - e_t^F$, in H banks. The net worth of the banker in period $t+1$ is $W_{t+1}^b = \zeta_t^w\left(\tilde{\rho}_{t+1}^F e_t^F + \tilde{\rho}_{t+1}^H\left(n_t^b - e_t^F\right)\right)$, where $\tilde{\rho}_{t+1}^F, \tilde{\rho}_{t+1}^H$ are the ex post gross returns on the inside equity invested in banks F and H, respectively. ζ_t^w is a shock that affects the bankers' wealth. It follows an $AR(1)$ process, $\log(\zeta_t^w) = \rho_{\zeta^w}\log(\zeta_{t-1}^w) + \varepsilon_{\zeta^w,t}$, $\varepsilon_{\zeta,t} \sim_{i.i.d} N\left(0, \sigma_{\varepsilon_{\zeta^w}}\right)$, where ρ_{ζ^w} is the persistence parameter. The maximization problem of the banker is to decide on the allocation of their initial wealth in order to maximize the expected wealth:

$$\max_{e_t^F} E_t\left(W_{t+1}^b\right) = E_t\zeta_t^w\left(\tilde{\rho}_{t+1}^F e_t^F + \tilde{\rho}_{t+1}^H\left(n_t^b - e_t^F\right)\right) \tag{B18}$$

An interior solution in which both types of banks receive positive equity requires that

$$E_t\tilde{\rho}_{t+1}^F = E_t\tilde{\rho}_{t+1}^H = \rho_t, \tag{B19}$$

where ρ_t denotes the required expected gross rate of return on equity investment at time t. This expected return is endogenously determined in equilibrium but it is taken as given by individuals and banks.

Banks

Banks are institutions that provide loans to households and entrepreneurs. There are two types of banks: banks indexed by H are specialized in mortgage loans and banks indexed by F are specialized in corporate loans. Both types of banks ($j = H, F$) issue equity bought by bankers and receive deposits from households.

Each bank maximizes the expected equity payoff, $\pi_{t+1}^j = \omega_{t+1}^j \tilde{R}_{t+1}^j b_t^j - R_t^D d_t^j$, that is, the difference between the return from loans and the repayments due to its deposits, where ω_{t+1}^j is an idiosyncratic portfolio return shock, which is i.i.d. across banks and follows a log-normal distribution with mean one and a distribution function $F^j(\omega_{t+1}^j)$, b_t^j and d_t^j are respectively the loans extended and deposits taken by bank at period t, R_{t+1}^D is the gross interest rate paid on the deposits taken in period t and $\tilde{R}_{t+1}^j$ is the realized return on a well-diversified portfolio of loans of type j.

Each bank faces a regulatory capital constraint:

$$e_t^j \geq \phi_t^j b_t^j \tag{B20}$$

where ϕ_t^j is the capital-to-asset ratio of banks of type j. The regulatory capital constraint states that the bank is restricted to back with equity at least a fraction of the loans made in period t. The problem of each bank j can be written as:

$$\pi_{t+1}^j = max\{\omega_{t+1}^j \tilde{R}_{t+1}^j b_t^j - R_t^D d_t^j, 0\} \tag{B21}$$

subject to the aforementioned regulatory capital constraint. In equilibrium, the constraint will be binding so that the loans and deposits can be expressed as $b_t^j = \frac{e_t^j}{\phi_t^j}$ and $d_t^j = (1 - \phi_t^j)\frac{e_t^j}{\phi_t^j}$, respectively. Accordingly, the threshold level of ω_t^j below which the bank defaults is $\overline{\omega}_{t+1}^j = \left(1 - \phi_t^j\right)\frac{R_t^D}{\tilde{R}_{t+1}^j}$ and the probability of default of each bank of type j is $F^j(\overline{\omega}_{t+1}^j)$. Thus, bank default is driven by fluctuations in the aggregate return $\tilde{R}_{t+1}^j$ and the bank idiosyncratic shock ω_{t+1}^j. In the case in which a bank defaults, its deposits are taken by DIA.

Given the above, the equity payoffs can then be written as:

$\pi_{t+1}^{j} = [\max\{\omega_{t+1}^{j} - \overline{\omega}_{t+1}^{j}, 0\}] \left(\frac{\tilde{R}_{t+1}^{j}}{\phi_t^{j}}\right) e_t^{j} = \left[\int_{\overline{\omega}_{t+1}^{j}}^{\infty} \left(\omega_{t+1}^{j} f^{j}\left(\omega_{t+1}^{j}\right)\right) d\omega_{t+1}^{j} - \overline{\omega}_{t+1}^{j} \int_{\overline{\omega}_{t+1}^{j}}^{\infty} \left(f^{j}\left(\omega_{t+1}^{j}\right)\right) d\omega_{t+1}^{j}\right] \times \left(\frac{\tilde{R}_{t+1}^{j}}{\phi_t^{j}}\right) e_t^{j}$
(B22)

where $f^{j}(\omega_{t+1}^{j})$ denotes the density distribution of ω_t^{j}. Then, the equity payoffs can be written as: $\pi_{t+1}^{j} = \frac{\left[1-\Gamma^{j}(\overline{\omega}_{t+1}^{j})\right]\tilde{R}_{t+1}^{j}}{\phi_t^{j}} e_t^{j}$ and the required ex post rate of return from the bankers that invest in the bank j is:

$$\tilde{\rho}_{t+1}^{j} = \frac{\left[1-\Gamma^{j}(\overline{\omega}_{t+1}^{j})\right]\tilde{R}_{t+1}^{j}}{\phi_t^{j}} \qquad \text{(B23)}$$

where $\Gamma^{j}\left(\overline{\omega}_{t+1}^{j}\right) = \int_0^{\overline{\omega}_{t+1}^{j}} \left(\omega_{t+1}^{j} f^{j}(\omega_{t+1}^{j})\right) d\omega_{t+1}^{j} + \overline{\omega}_{t+1}^{j} \int_{\overline{\omega}_{t+1}^{F}}^{\infty} \left(f^{j}(\omega_{t+1}^{j})\right) d\omega_{t+1}^{j}$ and

$G^{j}\left(\overline{\omega}_{t+1}^{j}\right) = \int_0^{\overline{\omega}_{t+1}^{j}} \left(\omega_{t+1}^{j} f^{j}(\omega_{t+1}^{j})\right) d\omega_{t+1}^{j}$.

Finally, the average default rate for banks can be written as:

$$PD_t^{b} = \frac{d_{t-1}^{H} F^{H}(\overline{\omega}_{t+1}^{H}) + F^{F}(\overline{\omega}_{t+1}^{F})}{d_{t-1}^{H} + d_{t-1}^{F}} \qquad \text{(B24)}$$

and the expression for the realized returns on loans after accounting for loan losses can be expressed as:

$$\tilde{R}_{t+1}^{H} = \left(\Gamma^{m}\left(\frac{x_t^{m}}{R_{t+1}^{H}}\right) - \mu^{m} G^{m}\left(\frac{x_t^{m}}{R_{t+1}^{H}}\right)\right) \left(\frac{R_{t+1}^{H} q_t^{H} h_t^{m}}{b_t^{m}}\right) \qquad \text{(B25)}$$

$$\tilde{R}_{t+1}^{F} = \left(\Gamma^{e}\left(\frac{x_t^{e}}{R_{t+1}^{K}}\right) - \mu^{e} G^{e}\left(\frac{x_t^{e}}{R_{t+1}^{K}}\right)\right) \left(\frac{R_{t+1}^{K} q_t^{K} k_t}{q_t^{K} k_t - n_t^{e}}\right) \qquad \text{(B26)}$$

Production sector

The final good in this economy is produced by perfectly competitive firms that use capital, k_t and labour, h_t. The production technology is:

$$y_t = A_t k_{t-1}^{a} l_t^{1-a} \qquad \text{(B27)}$$

where A_t is total factor productivity and a is the labour share in production.

Capital and housing production

Capital and housing producing firms are owned by patient households. Capital producers combine a fraction of the final good, I_t, and previous capital stock k_{t-1} to produce new units of capital goods that are sold to entrepreneurs at price q_t^K. The law of motion for the physical capital stock is given by:

$$k_t = (1-\delta \quad)k_{t-1} + \left[1 - S_K\left(\frac{I_t}{I_{t-1}}\right)\right] I_t \tag{B28}$$

where $S_K\left(\frac{I_t}{I_{t-1}}\right) = \frac{\xi_K}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$ is an adjustment cost function that satisfies $S(.) = S'(.) = 0, S''(.) = 0$.

The objective of the representative capital producing firm is to maximize expected profits:

$$E_t \sum_{i=0}^{\infty} (\beta^s)^i (\frac{c_t^s}{c_{t+i}^s}) \{q_{t+i}^K I_{t+i} - [1 + S^K(I_{t+i}/I_{t+i-1})]\, I_{t+i}\} \tag{B29}$$

Housing producers are modelled in a similar manner. In particular, the law of motion of the aggregate housing stock is:

$$h_t = \left(1-\delta^H\right)h_{t-1} + \left[1 - S_H\left(\frac{I_t^H}{I_{t-1}^H}\right)\right] I_t^H \tag{B30}$$

And the maximization problem of the representative housing producing firm is:

$$E_t \sum_{i=0}^{\infty} (\beta^s)^i (\frac{c_t^s}{c_{t+i}^s}) \{q_{t+i}^H I_{t+i}^H - [1 + S^K(I_{t+i}^H/I_{t+\iota-1}^H)]\, I_{t+i}^H\} \tag{B31}$$

Macroprudential policy

The macroprudential authority sets the capital requirements on bank lending in period t according to the following rule:

$$\phi_t^j = \bar{\phi}_0^j + \bar{\phi}_1^j\left[\log(b_t) - \log\left(\bar{b}\right)\right],\ j = H, F \tag{B32}$$

where b_t is the total credit in the economy at time t, $\bar{\phi}_0^j$ is the reference level of capital requirements and $\bar{\phi}_1^j > 0$ is a feedback parameter that captures the cyclical adjustments in capital requirements that depends on the state of the economy.

Deposit insurance agency (DIA)

The lump-sum taxes, T_t, imposed to households in order the DIA to cover the losses due to the default of H and F banks, are:

$$T_t = T_t^H + T_t^F\ , \tag{B33}$$

where,

$$T_t^H = [\overline{\omega}_t^H - \Gamma^H(\overline{\omega}_t^H) + \mu^H G^H(\overline{\omega}_t^H)]\tilde{R}_{t+1}^H(\frac{q_{t-1}^H h_{t-1}^m x_{t-1}^m}{R_{t-1}^m}) \tag{B34}$$

$$T_t^F = [\overline{\omega}_t^H - \Gamma^F(\overline{\omega}_t^F) + \mu^F G^F(\overline{\omega}_t^F)]\tilde{R}_{t+1}^F[q_t^K k_t - (1 - x^e)W_{t-1}^e] \tag{B35}$$

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