Housing market cycles, productivity growth, and household debt[*]

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Abstract

Housing market crashes are associated with household deleveraging and a very persistent decline in economic activity in an unbalanced panel of 50 countries. The persistence of the output response is driven by a slowdown in productivity growth and capital accumulation and is increasing in the amount of preexisting household debt. To interpret these stylized facts, I construct a two-agent (borrower-saver) dynamic general equilibrium model with occasionally binding collateral constraint tied to housing equity. Productivity grows endogenously in the model through forward-looking innovation investment. When the preexisting level of debt is sufficiently high, negative housing demand shocks cause collateral constraint to bind and trigger deleveraging. Endogenous slowdown in TFP growth emerges as one of the adjustment margins during this process, prolonging the real effects of a crisis. The initial shock is amplified by a negative feedback loop between deleveraging, borrowers' housing wealth and growth. I use the calibrated model to draw implications for macroeconomic policy during episodes of deleveraging.

JEL Codes: E32, E44, G01, O42, R21

Keywords: Business Cycles; Endogenous Growth; Financial Crises; Housing; Collateral Constraints; Occasionally Binding Constraints.

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1 Introduction

Recoveries from financial crises tend to be slow and incomplete (e.g. Cerra and Saxena 2008, Reinhart and Rogoff 2009). This became especially evident in the years after the global financial crisis of 2007-2008 as growth in many affected economies remained slow considerably longer than forecasters anticipated (figure 1). Popular explanations of the lackluster rebound from the crisis involve shortfalls in aggregate demand and prolonged private deleveraging (e.g. Blanchard et al. 2015, Lo and Rogoff 2015, Anzoategui et al. 2019). In particular, the Global Financial Crisis marked the end of the global household debt cycle that accompanied a rapid increase in housing prices worldwide (figure 2). The collapse of housing markets during the crisis had significant negative effects on the economy, including large drops in consumption, employment, and young-firm activity (Mian et al. 2013, Mian and Sufi 2014, Davis and Haltiwanger 2019).[1]

This paper contributes to the debate on the causes of persistent effects of financial crises by focusing on housing market boom-and-bust cycles. The sheer size of the housing and mortgage markets makes their interplay with the macroeconomy important. The majority of citizens in advanced countries own housing, it accounts for a lion's share of household wealth, and mortgage debt is the largest part of household debt.[2]

I first provide new evidence on the relation between housing market cycles, household debt, and total factor productivity (TFP) growth based on an unbalanced panel of 50 countries from 1950 to 2018. I perform two exercises: one that studies house price shocks in a panel VAR identified with short-run restrictions, and the other that consists of an event study of housing market crashes using the local projections method developed by Jordà (2005). Several conclusions emerge. Housing market boom-and-bust cycles are closely associated with household debt cycles. They predict a persistent decline in GDP level in the medium run. A growth accounting decomposition suggests that this persistent decline is primarily driven by slowdown in TFP growth. Quantitatively, these effects are sizable. For instance, for an average housing crash in my sample, the associated decline in the TFP level is around 2% a decade after the beginning of a crash. These results are not driven by the global financial crisis or other systemic financial crises that sometimes coincide with housing market crashes.

[1] Countries with the largest increases in household debt and housing prices in the years leading to the crisis tended to experience the biggest declines in consumption and growth once the cycle reversed (IMF 2012, Glick and Lansing 2010).

[2] For example, the home ownership rate in the US in Q3 2019 was 64.7%. In 2011 the median share of mortgages in household credit was about 70 percent across mostly developed countries, according to Cerutti et al. (2015). Among the G7 economies in 2010, the share of housing wealth in the total national wealth was in the range of 20-50%, according to Piketty and Zucman (2014).

The cross-country results are reinforced by the evidence of the persistent effect of the 2007 – 2010 housing market crash in the US on labor productivity growth. To estimate the effect I adopt two instrumental variables for house prices: the topology-based housing supply elasticity index of Saiz (2010) and the sensitivity instrument of Guren et al. (2018) that captures systematic differences in city-level exposure to regional house price cycles. Depending on the specification, the elasticity of cumulative 2007 – 2017 labor productivity growth to the 2007 – 2010 house prices decline falls in the range of 0.12 to 0.32. Given these results, a back-of-the-envelope calculation using the aggregate US data suggests that the housing market crash lowered the level of labor productivity by as much as 4.6% during the decade after 2007. As such, the detrimental effect of the housing market crash on the post-crisis productivity growth can account for more than 40% of the gap between the actual level of real per-capita GDP in 2017 and its pre-crisis trend.

In the second part of the paper, I interpret the empirical observations through the lens of a quantitative dynamic general equilibrium model, which I use to explore the channels through which the crisis propagated and to perform counterfactuals. The model combines elements from the literature on deleveraging with borrower-saver heterogeneity (Eggertsson and Krugman 2012), the literature on the role of collateral constraints tied to housing wealth (Iacoviello 2005, Guerrieri and Iacoviello 2017), and the literature on endogenous growth (Romer 1990, Comin and Gertler 2006). In particular, the model features representative borrower and saver households, occasionally binding collateral constraints tied to housing equity, endogenous growth driven by the introduction of new products, and nominal rigidity. Monetary policy conducted through interest rate setting subject to a zero-lower-bound constraint.

My modeling strategy is guided by the empirical evidence. First, the persistent decline in utilization-adjusted TFP in the aftermath of housing market crashes motivates the inclusion of the endogenous growth mechanism. Second, the evidence of household deleveraging and a significant interaction between preexisting household debt and the house price decline motivates my focus on household mortgage debt. As in standard quantitative macro models, inclusion of physical capital as a factor of production, subject to endogenous utilization, improves the ability of the framework to replicate the data. Finally, I abstract from the role of housing in production and the construction sector of the economy, assuming a fixed housing supply. As documented by Davis and Heathcote (2007), most of the fluctuations in house prices are driven by fluctuations in prices of residential land, of which there is ultimately a limited supply, and not by the price of structures.

Within this framework, I explore the aggregate effects of negative housing wealth shocks. Motivated by evidence from the existing literature, I resort to a housing preference (demand) shock as a source of exogenous variation in the price of housing. Liu et al. (2013) identified this shock as the one that drives most of the observed fluctuations in land prices and as important for generating empirically relevant comovement between land prices and investment. Furthermore, the estimates of Guerrieri and Iacoviello (2017) suggest that about 70% of the US consumption decline during the Great Recession can be attributed to housing demand shocks. More recently, Kaplan et al. (2019) argue that demand-side factors, but not changes in credit conditions, were the dominant force behind the U.S. housing market boom-and-bust cycle around the Great Recession.

When the preexisting level of debt is sufficiently high, negative demand shocks trigger the collateral constraint and cause deleveraging: credit-constrained households must reduce their spending to satisfy a lower borrowing limit. Under nominal rigidity in the short run, deleveraging leads to a sharp demand-driven contraction. However, over time, deleveraging affects the economys potential output as it slows the pace of capital and firm-creation investment. The shock thus acts like an aggregate demand shock in the short run, and like an aggregate supply shock in the medium run.

The calibrated model is successful in accounting for the empirical comovement between aggregate variables associated with housing market crashes. I calibrate parameters of the mortgage market and the balanced growth path (BGP) productivity growth to an average across economies in the cross-country panel under study. In addition, I directly use the empirical impulse responses to discipline several quantitative parameters of the model through impulse-response matching. The negative feedback loop between deleveraging, borrowers net worth, and growth appears to be strong enough to explain the entirety of the estimated aggregate dynamics associated with housing market crashes. The endogenous growth mechanism embedded in the model is key to its success by generating the empirically-relevant persistence in the responses of capital and TFP.

Specifically, I identify and illustrate four key channels of shock propagation that shape the general equilibrium response to housing demand shocks. Under nominal rigidity, borrowers deleveraging results in a demand-driven recession in the short run as the real interest rate does not adjust enough to cause savers to pick up the slack. I refer to this as the *aggregate demand channel*. This is especially pronounced when monetary policy is constrained by the zero lower bound, which significantly amplifies the effect of the shock. This short-run effect has the potential to leave deep scars on the level of economic activity through the *productivity growth channel*. The basic insight is that producer entry and product introduction is a form of investment, which responds to current and expected market conditions just like investment in physical capital does. Hence, changes in aggregate demand and credit availability affect entry and productivity growth. This is especially true for large recessions that occur in a high-leverage environment. Finally, two additional channels amplify the above effects. The first is a negative feedback loop between deleveraging and borrowers housing wealth: *Fisherian debt deflation channel*. The initial negative shock causes the collateral constraint to bind and trigger deleveraging. The resulting weak demand then exacerbates the damage to borrowers balance sheets and causes further deleveraging. The second is a negative feedback loop between future expected growth and current consumption: the *expected income growth channel*. Downward revisions in growth expectations weigh down current demand, which in turn further suppresses growth.

I conclude my study by employing the calibrated model to perform several policy counterfactuals. First, I ask how sensitive is the aggregate welfare cost of the shock to the stance of monetary policy. Both in the baseline model and in the counterfactual where without endogenous variations in growth, the welfare cost of the shock is most responsive to the strength of policy reaction to cyclical changes in output. Strong inflation targeting, in contrast, does little or nothing to improve welfare. In fact, for some combination of parameter values stronger reaction to inflation is welfare-reducing. The comparison to the counterfactual where endogenous variations in growth are shut down, shows that the endogenous productivity growth mechanism warrants stronger focus of monetary policy on the short-run output stabilization.

Turning to fiscal policy, I explore the effects of a policy that redistributes from savers to borrowers. In a narrow view, this policy can be considered as a debt forgiveness program. More broadly, it can be interpreted as a budget-neutral policy that shifts the tax burden from savers to borrowers. I demonstrate that this policy is effective in alleviating the negative feedback loop between deleveraging, asset prices, and productivity growth.

1.1 Contribution to the existing literature

My cross-country analysis adds to the existing literature on the real effects of financial and asset market cycles.[3] The empirical strategy I follow is closest to Jordà et al. (2015), who studied the short-run output dynamics following housing and equity-market crashes in a panel of developed countries. My analysis differs in its scope and focus. I significantly expand the number of events in the study and explore the dynamics of a broader set of macroeconomic variables. More substantively, I focus on the persistent dynamics od aggregate variables and identify their potential drivers. Using the harmonized cross-country data on household and

[3] See Bordo and Haubrich (2010), IMF (2012), Jordà et al. (2013), Jordà et al. (2015), Krishnamurthy and Muir (2017), Lombardi et al. (2017), Romer and Romer (2017).

corporate debt, I emphasize the role of household indebtedness.

Furthermore, my empirical analysis is also related to the existing literature that demonstrated that the deterioration of household balance sheets during the 2006-09 housing market collapse in th US played a significant role in the sharp decline in employment and consumption (Mian et al. 2013, Mian and Sufi 2014).[4] The evidence from US metropolitan statistical areas that I present suggests that the implications of the housing market's crash for the US economy extend far beyond the contemporaneous effect; rather, the legacy of the crash lingers to this day.

Finally, this paper also relates to the broader literature that explores the nexus between the housing market dynamics and business dynamism. Recent contributions provide evidence of a causal relationship between homeowner housing wealth and young-firm activity (Davis and Haltiwanger 2019), as well as on the probability of homeowners becoming entrepreneurs (Corradin and Popov 2015, Schmalz et al. 2017). According to such work, a significant fall in housing prices causes a slowdown in startup activity. Periods when entry is especially weak consequently result in a missing generation of firms, which may have a very persistent effect on output and measured productivity (Gourio et al. 2016).[5]

This paper theoretically relates to several bodies of existing literature. Similar to the literature on deleveraging crises pioneered by Eggertsson and Krugman (2012), recession in my model is a result of a reduction in the borrowing capacity of debtor households.[6] Differently from this literature, however, the borrowing limit is not exogenous, but it is tied to the borrowers' housing wealth determined in general equilibrium. This feature connect the paper to the body of literature on the macroeconomic effects of home equity-based borrowing started by Iacoviello (2005).[7] The implications of treating the borrowing limit as endogenously determined are far from trivial. This approach allows the model to account for the amplification effect through the two-way interactions between deleveraging, borrower housing wealth, and economic activity. This effect is state-dependent, shaped by the policy response, and very important quantitatively.

[4] Andersen et al. (2014) and Bunn et al. (2015) identify similar patterns in the data from Denmark and U.K. respectively. Overall, changes in household debt correlate stronger with growth than changes in corporate debt, both in developed and developing countries, as documented by Bahadir and Gumus 2016 and Mian et al. 2017.

[5] To put this statement in context, the U.S. establishment entry rate plummeted by 26% between 2006 and 2009, according to the CENSUS Business Dynamics Statistics.

[6] See also Benigno and Romei (2014), Benigno et al. (2020), Guerrieri and Lorenzoni (2017), and Korinek and Simsek (2016).

[7] Other important contributions include Ferrero (2015), Jensen et al. (2019), Justiniano et al. (2015), Liu et al. (2013), Liu et al. (2016), Midrigan and Philippon (2018), Iacoviello and Minetti (2006), and Iacoviello and Neri (2010).

Empirically, episodes of household deleveraging during housing market crashes are associated with very persistent declines in economic activity. I interpret this observation building on insights from the literature on the interconnectedness between business cycles growth.[8] Much of the recent theoretical literature on this topic builds on the seminal contribution of Comin and Gertler (2006).[9] In particular, particularly large contractions and slow recoveries in many countries after the Global Financial Crisis have motivated research on the role endogenous growth and financial shocks in generating such persistence.[10] So far, the existing literature to date has either focused on financial frictions that directly affect financing of innovations (Queralto 2019, Guerron-Quintana and Jinnai 2019, Ikeda and Kurozumi 2018) or remained agnostic about the source of the financial shock all together, treating it as exogenous (Anzoategui et al. 2019). I contribute to this debate by investigating the persistent effects of household deleveraging generated by negative housing demand shocks.

I approach the issue of persistent effects of business-cycle fluctuations with a particular focus on the house equity-based borrowing. This is complementary to the alternative mechanisms proposed in the literature. Persistent effects of temporary shocks may also stem from the labor market dynamics (Blanchard and Summers 1987, Acharya et al. 2018); purely from self-fulfilling expectations of low growth (Benigno and Fornaro 2018). A number of papers emphasize the role of firm dynamics. Ates and Saffie (2020) document that firms born during the credit shortage are fewer, but more productive. Schmitz (2017) focuses on how tight financial conditions cause small and young innovating firms reduce their R&D resulting in R&D misallocation.[11]

Finally, this work also contributes to the literature on the non-linear effects of occasionally binding constraints (OBCs). The closest reference is Guerrieri and Iacoviello (2017), who show that a model with an OBCs tied to housing wealth makes it possible to account for the asymmetry in the link between housing prices and consumption growth during the latest

[8] See Campbell and Mankiw (1989), Fatás (2002), Nelson and Plosser (1982), and Ramey and Ramey (1995) for the evidence against the separation between business cycle and growth, traditional in macroeconomics.

[9] See later contributions by Bianchi et al. (2019), Comin et al. (2014), Correa-López and de Blas (2018), Croce et al. (2012), Garga and Singh (2020), Gornemann (2015), Holden (2016), Moran and Queralto (2018), Queralto (2019). Recently, endogenous growth mechanisms have also been used in the finance literature. By generating a small but persistent endogenous productivity component, this feature has been shown to improve the asset-pricing implications of dynamic general equilibrium models, see Bocola and Gornemann 2013, Gavazzoni and Santacreu 2020, Guerrón-Quintana et al. 2019, and Kung and Schmid 2015 among others.

[10] Fernald et al. (2017) and Gordon (2015) point out that that the productivity growth slowdown in the U.S. economy that followed the crisis has started before the Great Recession and argue that the dynamics in the recent years is the continuation of a secular trend. Similar observations have been made about European countries. In this context, the question is not why there seems to be a secular decline in output growth, but whether the global financial crisis has accelerated an existing trend.

[11] See also Garcia-Macia (2015), Knowles (2018), and Kozlowski et al. (2019).

housing market cycle in the US[12]

Outline. The rest of the paper is organized as follows. Section 2 discusses the empirical evidence on short-run and persistent effects of housing crashes. Section 3 presents the model. Section 4 discusses calibration and the ability of the model to account for the empirical evidence. 5 explores the key mechanisms driving the dynamics. Section 6 draws implications for monetary and fiscal policy. Section 7 concludes.

2 Empirical evidence

This section provides a detailed cross-country account of the macroeconomic effects of housing price shocks. Specifically, my main interest is whether housing market boom and bust cycles are systematically associated with subsequent slower total factor productivity growth. To address this question I construct an unbalanced panel of macroeconomic variables covering 50 countries from 1950 to 2018. The data set includes aggregate house price indices, measures of private credit, and a comprehensive set of macroeconomic indicators. The real economy part of the data set heavily relies on the latest (9.1) release of the Penn World Table, Feenstra et al. (2015). Private debt to GDP ratios are primarily from the IMF's Global Debt Database, Mbaye et al. (2018). Where applicable, the debt-to-GDP series are extended backward using growth rates of private loans from Jorda et al. (2016) Macrohistory database. Real house price indices combine the data from BIS, Dallas FED, OECD, and Jorda et al. (2016) Macrohistory databases. Please refer to Appendix A for further details on data sources and summary statistics.

In addition, I construct utilization-adjusted TFP series based on the data from the Penn World Table and using the procedure discussed in Imbs (1999). This method filters out cyclical variations in labor and capital utilization using a partial-equilibrium version of Burnside and Eichenbaum (1996) that allows for factor hoarding. It is an alternative to the approach of Basu et al. (2006) that utilizes industry-level data to also account for nonconstant returns to scale and aggregation effects. Unfortunately, data limitations make the use of the latter method infeasible on a cross-country scale. However, I show that US annual factor utilization growth implied by my calculations closely follows the estimate based on Basu et al. (2006) methodology.

[12] OBCs are also a central ingredient of small open economy models designed to study sudden stops and macroprudential policy, see Akinci and Chahrour (2018), Benigno et al. (2016), Bianchi and Mendoza (2018), Korinek (2018), and Mendoza (2010). The models in these papers account for financial crises — periods when credit constraints of borrowers bind — as rare events nested within the regular business cycle.

Appendix D.1 discusses the procedure in detail.[13]

2.1 Panel VAR

I first use a panel VAR to characterize the comovement between house prices, household debt, and TFP. The model includes country fixed effects to account for time-invariant cross-country heterogeneity. I resort to the pooled estimator due to the limited time dimension of the data from some countries. All variables enter the model in levels to account for the potential near cointegration of the unknown form between them.

The existing macroeconomic literature that suggests that housing demand shocks are the main driving force of house price fluctuations.[14] I identify housing demand shocks by short-run restrictions ordering the variables as follows: log utilization-adjusted TFP index, household debt to GDP, and log real house price. The ordering implies that house price and household debt shock do not have a contemporaneous effect on TFP and that house price shocks do not have a contemporaneous effect on household debt. In other words, housing demand shocks are identified as house price shocks that are orthogonal to household credit shocks and do not have a contemporaneous effect on the real economy to rule out more fundamental shocks.

Figure 3 presents responses of the system to a 1% positive house price shock. A temporary house price increase is contemporaneously associated with a household debt boom and no significant response of the utilization-adjusted TFP. Over time house prices and household debt revert back towards their initial levels. This boom-and-bust dynamics predicts a persistent decrease in the TFP level in the medium run, which reaches 0.06% 15 years after the initial 1% house price shock. This is a sizable effect considering the magnitude of housing market cycles. For instance, the US real house price has increased by around 35% from 2000 to 2006.

These results highlight two key points. First, housing market boom-and-bust cycles predict slower future TFP growth. Second, the relation between house prices and the macroeconomy is asymmetric. The bust part of the cycle has significant negative effects, while the boom is not contemporaneously associated with accelerated productivity growth.

[13] See other applications of the Imbs (1999) correction in Taylor et al. (2020) and Levchenko and Pandalai-Nayar (2018).

[14] See Guerrieri and Iacoviello (2017) and Liu et al. (2013), among others.

2.2 Event analysis: history of housing market crashes

Next, I take a closer look at macroeconomic dynamics associated with major housing market boom and bust events, which I then use as a basis for the modeling exercise of the next section. My approach is similar to the event analysis of Jordà et al. (2015). Studying large and sudden house price declines is appealing for several reasons. During these1 periods the house price dynamics is more likely to be an important independent factor affecting the macroeconomy. Moreover, as emphasized by Guerrieri and Iacoviello (2017), the relation between house prices and economic activity is asymmetric and state-dependent due to the presence of occasionally binding collateral constraints tied to housing wealth. The macroeconomic effects of house price shocks are likely to be the largest during housing market crashes.

I first use the constructed cross-country panel of real house price indices to determine periods of housing market crashes. Similarly to Jordà et al. (2015), my strategy consists of two steps. First, the aggregate house price index needs to be sufficiently elevated relative to the long-run trend defined using an HP filter.[15] Second, the price index needs to sharply fall from the peak. As a rule of thumb, I use the threshold of at least a 10% decline in the first three years after the peak. To put this threshold in perspective, the US aggregate real housing price index fell by around 14% during the first three years from the peak in 2006. This second step intends to filter out "soft landing" situations when the rapid house price growth was not followed by an equally rapid correction. Appendix A presents an illustration of the definition. The above procedure identifies 63 events, 39 of which happened before the Global Financial Crisis. Table 1 presents the full list. On average, the price decline continues for 5 years and reaches -31% peak to though with two-thirds of this decline occurring in the first three years. To assess macroeconomic dynamics associated with these events, I construct a housing market crash measure as follows: $\Delta p_{i,t}^{\text{crash}} = \log(P_{i,t+2}) - \log(P_{i,t-1})$. For each event in a country i it equals the cumulative house price decline during the first three years from the peak at $t-1$.

I estimate elasticities of macroeconomic variables to the house price decline using the following dynamic cross-country panel:

$$\Delta_h y_{i,t+h} = \alpha_i^h + \alpha_t^h + \beta^h \Delta p_{i,t}^{\text{crash}} + X_{i,t}\Gamma + \varepsilon_{it}^h \qquad (1)$$

The dependent variable is the country i's h-period log difference of the response variable: $\Delta_h y_{i,t+h} = \log(Y_{i,t+h}) - \log(Y_{i,t})$; and $\Delta p_{i,t}^{\text{crash}}$ is the housing crash measure described above. Estimating this relation at different horizons produces a set of coefficients $\{\beta^h\}_{h=1:H}$ that can

[15] I use the smoothing parameter of $400000/4^4$ for annual observations similar to the definition of credit cycles by the BIS.

be interpreted as elasticities of the dependent variable to the house price decline over time, conditional on the set of controls described below. This estimation strategy effectively follows the local projections approach of Jordà (2005).

The baseline specification includes country and year fixed effects, α_i^h and α_t^h respectively. $X_{i,t}$ contains a variety of other country-level controls. It includes values at the peak of a housing market cycle and one lag of (1) the response-variable growth rate; (2) real per-capita investment growth, (3) GDP-deflator inflation rate, (4) net exports to GDP ratio, (5) real house price growth rate. In addition, to control for the possible effect of an exchange-rate regime, I include fixed exchange rate indicators from Ilzetzki et al. (2019). Many but not all housing market crashes coincide with broad financial crises. I include Laeven and Valencia (2013) indicators of systemic banking and currency crisis to account for that. Finally, I use the investment to GDP ratio to control for the overall investment intensity of an economy.

Figure 4 presents the resulting dynamics of variables associated with housing market crashes. Several key observations emerge. First, the studied events are associated with a broad decline in economic activity. At the trough of the contraction, the 1.45% decline in house price is associated with a decline in consumption larger than output (-0.22% and -0.32% respectively) and a -0.67% decline in investment. Second, the decline in economic activity is associated with households deleveraging: the household debt-to-GDP falls by about 0.21%. Finally, the house price decline predicts a very persistent decrease in the levels of output and consumption.[16] The growth accounting decomposition suggests that the sluggish dynamics of capital accumulation and TFP growth are the primary drivers of this dynamics. While the employment-to-population ratio recovers by year 6, declines in the capital stock and TFP remain significant even 10 years after the housing market peak. The elasticity of TFP to the house price decline from the peak is quantitatively close to the one uncovered by a panel VAR of the previous section. During an average crash in a sample, a 1.5% fall of the house price is associated with a 0.1% fall in utilization-adjusted TFP in the medium run.

The online appendix gathers some additional results. Appendix B.1 includes responses of additional macroeconomic variables. Housing market crashes are associated with a significant external adjustment with persistent improvement in the trade balance and depreciation of the real exchange rate. Responses of the Solow residual and GDP per worker are consistent with the results discussed above and the core conclusions are robust to excluding observations after 2006. Additionally, in appendix B.2 I discuss the role of preexisting private credit imbalances in shaping the macroeconomic dynamics associated with housing market crashes. I show that a

[16] In fact, they last longer than conventional business cycles. King and Rebelo (1999) define the business cycle component as frequencies from 2 to 32 quarters extracted using the Band Pass filter.

larger household debt-to-GDP gap at the peak of the housing market cycle predicts deeper and more persistent contraction. On the other hand, non-financial corporate debt does not have such predictive power.

2.3 The effect of the 2007 housing market crash across US MSAs

The cross-country evidence of preceding sections provides important insights on the relationship between housing prices and the macroeconomy, in particular the fact that housing market crashes predict subsequent lower TFP growth. However, one should be cautious to avoid placing a strong causal interpretation of the results. Rather, they illustrate the equilibrium comovement between variables of interest. To reinforce this result, I also present evidence of the negative effect of the housing market crash on labor productivity growth across US Metropolitan Statistical Areas (MSAs). The larger cross-sectional dimension of the data along with the availability of instrumental variables for house price growth allows us to estimate the effect more precisely.

Panel (a) of figure 5 shows a negative correlation between the magnitude of the housing market crash and the cumulative growth of real GDP per worker from 2007 to 2017 across states and MSAs. House price growth is based on FHFA all-transactions house price indexes and the real-economy data is from the BEA. To estimate the effect of the house price shock on labor productivity growth, I adopt two instrumental variables proposed in the literature. The first is the Saiz (2010) housing supply elasticity index, which captures geographical and regulatory constraints to construction.[17] Additionally, I use the regional sensitivity instrument developed by Guren et al. (2018). Their approach exploits the fact that house prices in some cities are systematically more sensitive to regional housing cycles than in others. By explicitly controlling for local macroeconomic factors, the authors construct an instrument stronger than the housing supply elasticity index. Moreover, the instrument is available for a larger number of MSAs than the housing supply elasticity.

The baseline specification for the cross-section of MSAs is the following:

$$\Delta lp_i = \alpha + \eta \widehat{\Delta p_i^H} + X_i'\Gamma + \varepsilon_i \tag{2}$$

where $\Delta lp_i = \log(LP_{i,2017}) - \log(LP_{i,2007})$ is the log difference of labor productivity defined as real GDP per worker; $\widehat{\Delta p_i^H}$ is the instrumented log difference of the house price index

[17] This instrument is widely used in the literature, see Mian et al. (2013), Mian and Sufi (2014), Giroud and Mueller (2017), Davis and Haltiwanger (2019), among others. Although common, the use of this instrument has been a subject of controversy lately, see a discussion in Davidoff (2013).

$\Delta p_i^H = \log(P_{i,2010}^H) - \log(P_{i,2007}^H)$; and X_i' includes local industry structure controls and per capital personal income. The parameter of interest is η: the elasticity of labor productivity growth to the decline in house price during the housing market crash.

Panel (b) of figure 5 reports η across a number of specifications. Depending on the specification, the elasticity of the cumulative labor productivity growth (2007 – 2017) to the decline in house price (Q1 2007 – Q1 2010) ranges from 0.12 to 0.32. For illustrative purposes, let me pick elasticity of 0.2 within this range. One way to put this estimate in perspective is to consider aggregate data. In 2017, US real per capita GDP was about 10% below the pre-crisis trend (figure 1). How much of this gap can be explained by the negative effect of the housing market crash? The US aggregate house price fell by 14.4% from Q1 2007 to Q1 2010, according to the FHFA all-transaction index. The elasticity of 0.2 then implies that the loss of labor productivity in the decade since 2007 driven by the fall in house prices during the 2007-2010 crash is equal to 2.88%. In other words, almost 30% of the gap between the actual US real GDP and the pre-crisis trend can be accounted for by the negative effect of the housing market crash on labor productivity growth.

Appendix B.3 gathers some additional results, including first-stage regressions and specifications with housing net worth shock from Mian and Sufi (2011) instead of the house price decline. It also shows that the relationship between house price dynamics and labor productivity growth is asymmetric: the boom phase of the latest US housing market cycle was not associated with an increase in productivity growth.

3 The model

In this section, I develop a dynamic general equilibrium model that provides an interpretation for the empirical evidence of the previous sections. I will use the model for the exercises in the remainder of the paper. The core of the setup is a Woodford (2003) cashless economy with capital accumulation and monetary policy conducted through interest rate setting. This framework is extended along two dimensions. First, instead of a representative household the model features two agents: borrowers and savers that differ in their discount factors. The accumulation of household debt in the US and other developed countries in the recent decades increasingly has been financed by savings of rich households, as Mian et al. (2020) suggest. Both saver and borrower households supply labor, trade risk-free bonds, and hold housing, which generates a utility flow. Borrowers are subject to an occasionally binding collateral constraint tied to their housing wealth (Kiyotaki and Moore 1997, Iacoviello 2005). Borrowers also have an access to investment opportunities: they accumulate capital and finance product creation. As suggested by Eggertsson and Krugman (2012), borrowers should not necessarily be interpreted as "liquidity-constrained poor", as is common in the literature. Instead, they can be broadly interpreted as those who have an access to investment opportunities and are in need of external funding, which is constrained by the debt limit. In my model, this assumption makes holders of capital and equity levered. As a result, investment and product creation become additional margins of adjustment to deleveraging along with consumption spending. Second, the model features productivity growth through expanding variety of intermediate products, broadly interpretable as horizontally differentiated innovations (Romer 1990, Comin and Gertler 2006).[18] Figure 6 presents a flow chart of the model that summarizes its key participants and their interactions.

3.1 Households

There are two types of households: savers and borrowers denoted by a superscript $H \in \{S, B\}$. A common way in the literature to motivate borrowing and lending is to assume that savers are more patient than borrowers $\beta_S > \beta_B$.[19]

Each household gains utility from consumption and the stock of housing in its possession, and disutility from labor: $U(C_t^H, L_t^H) + G(h_t^H)$. I assume Greenwood et al. (1988) period utility function in consumption and labor: $U(C_t^H, L_t^H) = \left(\left(C_t^H - \Upsilon_t \frac{(L_t^H)^{1+\epsilon_L}}{1+\epsilon_L}\right)^{1-\sigma} - 1\right)/(1-\sigma)$, where the aggregate consumption is a CES basket of differentiate retail goods $C_t^H = \left(\int_0^1 C_t^H(j)^{\frac{\eta-1}{\eta}} dj\right)$, and the two parameters, σ and ϵ_L, are the inverse elasticity of intertemporal substitution and the inverse Frisch elasticity of labor supply respectively. The GHH preference abstracts from the wealth effect in labor supply, this assumption allows to avoid a counterfactual dynamics of borrowers labor supply during periods when they are credit-constrained. As in Queralto (2019), the disutility of labor is governed by the following process:[20]

$$\Upsilon_t = \Upsilon_{t-1}^{\rho_\Upsilon} N_t^{1-\rho_\Upsilon} \tag{3}$$

[18] This variety-based approach differs from the quality ladder growth models of Grossman and Helpman (1991) and Aghion and Howitt (1992), where endogenous growth takes a form of repeated quality improvements over the pre-fixed number of varieties. However, as Grossman and Helpman (1991) note, these two frameworks result in very similar reduced forms.

[19] An alternative but conceptually similar way to ensure that borrowers do not self-finance in the long run is to assume that they are finitely-lived. See, for example, the formulation of bankers problem in Gertler and Karadi (2011).

[20] Jaimovich and Rebelo (2009) suggest a similar preference that allows to parameterize the short-run wealth effect on the labor supply

The parameter ρ_Υ determines the responsiveness of disutility of labor to changes in productivity growth. This formulation insures that the BGP with constant hours exists, but the medium-run swings in growth do not excessively affect labor supply.[21]

As common in the literature, utility from housing is assumed to be separable from consumption and labor. I assume that it takes the standard CRRA form $G(h_t^H) = \kappa_t \vartheta_t \frac{(h_t^H)^{1-\epsilon_h}-1}{1-\epsilon_h}$, where ϵ_h is the inverse elasticity of housing demand; κ_t is the weight of housing in the total period utility, which is allowed to exhibit trend to ensure that the marginal rate of substitution between consumption and housing is constant on the balanced growth path; and ϑ_t is a housing preference shock.

3.1.1 Saver households

Saver households supply labor L_t^S; earn wage W_t; consume the aggregate basket of goods C_t^S; trade nominal risk-free bonds B_{t+1}^S; and adjust their housing stock h_t^S at a price P_t^h per unit. The representative household maximizes its expected discounted lifetime utility subject to the budget constraint:

$$\max_{\{C_{t+j}^S, L_{t+j}^S, h_{t+j}^S, B_{t+1+j}^S\}_{j=0}^{\infty}} \quad \mathbb{E}_t \sum_{j=0}^{\infty} \beta_S^j \left(U(C_{t+j}^S, L_{t+j}^S) + \kappa_t \vartheta_t G(h_{t+j}^S) \right) \qquad \text{s.t.}$$

$$C_t^S + P_t^h (h_t^S - h_{t-1}^S) + (1 + r_{t-1}) \frac{B_t^S}{P_t} = W_t L_t^S + \frac{B_{t+1}^S}{P_t} \tag{4}$$

From now on, let λ_t^H denote the household H's Lagrange multiplier with respect to the budget constraint, and $\Lambda_{t,t+1}^H = \beta_h \frac{\lambda_{t+1}^H}{\lambda_t^H}$ denote the households stochastic discount factor. The intertemporal optimality condition, labor supply, and housing demand implied by the saver household's optimization problem are as follows:

$$\mathbb{E}_t \left(\Lambda_{t,t+1}^S \frac{1 + r_t}{\Pi_{t+1}} \right) = 1 \tag{5}$$

$$W_t = \Upsilon_t (L_t^S)^{\epsilon_L} \tag{6}$$

$$P_t^h = \mathbb{E}_t \left(\Lambda_{t,t+1}^S P_{t+1}^h \right) + \kappa_t \vartheta_t \frac{(h_t^S)^{-\epsilon_h}}{\lambda_t^S} \tag{7}$$

The first two conditions are standard. Equation (7) is the housing demand condition, which implies that the current real hosing price (P_t^H) equals to the expected discounted lifetime stream

[21] One way to interpret this feature of the preference is as follows. As noted by Benhabib et al. (1991), the GHH preference can be interpreted as a reduced form of an economy with home production. The disutility of work then consists of the forgone output in home production. This disutility increases as productivity improvements in the formal sector spill over to the home production. However, to the extent this process takes time, disutility of labor exhibits inertia.

of utility from housing expressed in the units of the consumption good.

3.1.2 Borrower households

Similarly to savers, borrower households supply labor, consume, trade nominal risk-free bonds, and demand housing. Moreover, they have an access to investment opportunities. They accumulate capital and, as in Bilbiie et al. (2012), hold shares in a mutual fund of intermediate firms. In each period t the household buys ι_{t+1} shares in a mutual fund of $N_t + N_{e,t}$ firms (already operating and new entrants) at the price v_t per share; receive the dividend income from currently owned firms d_t, as well as the return on the shares purchased in the previous period. Finally, as Greenwood et al. (1988) I endogenize capital utilization by assuming that the depreciation rate of capital is an increasing function of utilization. This quantitative feature is important for capturing the short-run dynamics of measured TFP.

The amount these households can borrow from savers (B_t^B) is subject to a Kiyotaki and Moore (1997) type occasionally binding collateral constraint: the household cannot borrow more than a fraction m of the current value of its housing stock $P_t^h h_t^B$.[22] Note that I do not impose that the household is constrained per se. Whether the collateral constraint binds or not would be determined in equilibrium depending on the state of the economy. As in Guerrieri and Iacoviello (2017), the borrowing limit does not reset within one period, parameter ρ_B governs the degree of its persistence. This quantitative feature allows to capture the empirically-relevant gradual adjustment of the borrowing capacity in response to changes in borrowers housing wealth.[23]

The full program of borrowers takes the following form:

$$\max_{\{C^B_{t+j}, L^B_{t+j}, h^B_{t+j}, B^B_{t+1+j}\}_{j=0}^{\infty}} \quad \mathbb{E}_t \sum_{j=0}^{\infty} \beta_B^j \left(U(C^B_{t+j}, L^B_{t+j}) + \kappa_t \vartheta_t G(h^B_{t+j}) \right) \qquad \text{s.t.}$$

[22] Following the existing literature, I do no explicitly model the origins of this constraint. A natural interpretation, however, should be that due to the imperfect enforceability of contracts, the ability of households to borrow is bounded by a fraction of the value of their collateral assets that can be seized by creditors in a case of default. The parameter m can be narrowly interpreted as the maximum loan-to-value (LTV) ratio. It can also be linked to the degree of country's financial markets development, as suggested by some of the existing literature.

[23] A natural interpretation of this feature is the implicit existence of multi-period credit contracts, as in Kydland et al. (2016).

$$
\begin{aligned}
&C_t^B + I_t + P_t^h(h_t^B - h_{t-1}^B) + (1+r_{t-1})\frac{B_t^B}{P_t} + \iota_{t+1}v_t(N_t + N_{e,t}) = \\
&\qquad \iota_t(v_t + d_t)N_t + W_t L_t^B + R_t^K u_t K_t + \frac{B_{t+1}^B}{P_t} + div_t
\end{aligned} \tag{8}
$$

$$
\frac{B_{t+1}^B}{P_t} \leq \rho_B \frac{B_t^B}{P_{t-1}} + (1-\rho_B) m P_t^h h_t^B \tag{9}
$$

$$
K_{t+1} = (1 - \delta_K(u_t))K_t + (1 - AC_{I,t})I_t \tag{10}
$$

$$
\delta_K(u_t) = \delta_K + c_1(u_t - 1) + \frac{c_2}{2}(u_t - 1)^2 \tag{11}
$$

Let $\chi_t \geq 0$ be the Lagrange multiplier with respect to the borrowing constraint (9), then the Euler equation with respect to bonds is:

$$
\mathbb{E}_t \left(\Lambda_{t,t+1}^B \frac{1 + r_t - \rho_B \chi_{t+1}}{\Pi_{t+1}} \right) = 1 - \chi_t \tag{12}
$$

Binding collateral constraint, $\chi_t > 0$, creates an endogenous wedge between the real interest rate and the borrowers intertemporal marginal rate of substitution in consumption. In other words, the consumption path of the credit-constrained borrowers deviates from the one predicted by the real interest rate dynamics.

Next, borrowers housing demand is:

$$
P_t^h = \mathbb{E}_t \left(\Lambda_{t,t+1}^B P_{t+1}^h \right) + \kappa_t \vartheta_t \frac{(h_t^B)^{-\epsilon_h}}{\lambda_t^B} + \chi_t (1 - \rho_B) m P_t^h \tag{13}
$$

The expression is symmetric to savers housing demand, equation (7), except for the last term. Its interpretation is the following: the *direct* effect of borrowers being credit-constrained ($\chi_t > 0$) is that they value a marginal unit of housing more since it has an additional benefit of relaxing their borrowing limit. However, the general equilibrium effect of the binding borrowing constraint on their housing demand is the opposite. I postpone the detailed discussion of this effect until section (5.3).

The first order condition with respect to share holdings ι_{t+1} implies the following expression:

$$
v_t = (1 - \delta_N)\, \mathbb{E}_t \left(\Lambda_{t,t+1}^B (d_{t+1} + v_{t+1}) \right), \tag{14}
$$

When iterated forward, it produces the standard firm value equation: $v_t = \mathbb{E}_t \sum_{j=0}^{\infty} \Lambda_{t,t+j}^B (1 - \delta_N)^j d_{t+j}$. The present firm value equals to its expected discounted profit stream, accounting for the fact that each period a firm faces an exogenous probability of exiting the market δ_N, as discussed further.

The optimality conditions for accumulation and utilization of capital are standard:

$$q_t = \mathbb{E}_t\left(\Lambda^B_{t,t+1}((1-\delta_{K,t})q_{t+1} + R^K_{t+1})\right) \tag{15}$$

$$q_t = 1 + q_t(AC_{I,t} + AC'_{I,t}I_t) - \mathbb{E}_t\left(\Lambda^B_{t,t+1}q_{t+1}AC'_{I,t+1}I_{t+1}\right) \tag{16}$$

$$R^K_t = c_1 + c_2(u_t - 1) \tag{17}$$

where q_t is Tobin's q: the Lagrange multiplier with respect to the capital law of motion (10). Capital investment is subject to a quadratic adjustment cost $AC_{I,t} = \frac{\psi_K}{2}\left(\frac{I_t}{I_{t-1}g} - 1\right)^2$, where ψ_K governs the size of the adjustment cost and g in the BGP growth rate.

Finally, the labor supply condition is symmetric to the one of savers:

$$W_t = \Upsilon_t(L^B_t)^{\epsilon_L} \tag{18}$$

3.2 Production

The production structure of the economy consists of two upstream and two downstream sectors. The upstream sectors are the production sector that employs labor, capital and a basket of intermediate good, and a sector of intermediate-good suppliers. The downstream sectors are the wholesale and retail sectors that differentiate the production-sector good and distribute it to final consumers. Moreover, a sector of innovators invents blueprints of intermediate goods. Nonrivalry of ideas generated by innovators is the source of endogenous growth in the economy. Given the focus of the paper, I abstract from the role of housing in production.

3.2.1 Production sector

The production sector is populated by perfectly competitive firms that employ homogeneous labor supplied by both households, $L_t = L^S_t + L^B_t$, effective capital, $\tilde{K}_t = u_t K_t$, and a CES basket of intermediate products with elasticity of substitution $\frac{\nu}{\nu-1}$, $X_t = \left[\int_0^{N_t} x_t(\omega)^{\frac{1}{\nu}} d\omega\right]^\nu$. Positive externalities in the innovation sector, as discussed further, cause the mass of intermediate products, N_t, to expand over time. This brings about efficiency gains to diversity implied by the CES aggregator and increases the measured TFP. As in Comin and Gertler (2006), the aggregate production function takes the following form:

$$F_t = Z_t\left(\tilde{K}_t^{\alpha} L_t^{1-\alpha}\right)^{1-\xi} X_t^{\xi} = Z_t\left(\tilde{K}^{\alpha}_t L^{1-\alpha}_t\right)^{1-\xi}\left(\int_0^{N_t} x_t(\omega)^{\frac{1}{\nu}} d\omega\right)^{\nu\xi}$$

Given input prices, the representative firm maximizes its expected profit stream (expressed in units of the consumption good):

$$\max_{\{x_{t+j}(\omega),L_{t+j},K_{t+j}\}_{j=0}^{\infty}} \quad \mathbb{E}_t \sum_{j=0}^{\infty} \Lambda^B_{t,t+j} \left[p^F_t F_{t+j} - R^K_{t+j}\tilde{K}_{t+j} - W_{t+j}L_{t+j} - \int_0^{N_t} p^x_{t+j}(\omega)x_{t+j}(\omega)d\omega \right]$$

The problem implies the following input demands:

$$W_t = p^F_t(1-\alpha)(1-\xi)\frac{F_t}{L_t} \tag{19}$$

$$R^K_t = p^F_t\alpha(1-\xi)\frac{F_t}{\tilde{K}_t} \tag{20}$$

$$p^x_t(\omega) = p^F_t\xi\frac{F_t}{X_t}x_t(\omega)^{\frac{1-\nu}{\nu}}$$

where $p^F_t = \frac{P^F_t}{P_t}$ and $p^x_t(\omega) = \frac{P^x_t(\omega)}{P_t}$ are relative prices of the production-sector and the intermediate-sector goods respectively.

3.2.2 *Intermediate-good sector*

The intermediate sector is populated by a mass $[0, N_t]$ of monopolistically competitive firms, each operating a roundabout technology that requires A^{-1} units of the domestic good to produce a unit of the intermediate good. One should not take this setup literally. The correct interpretation of this formal description is that the forgone final good is never manufactured. The resources that would have been used to produce the forgone output are used instead to manufacture intermediate goods.

Each intermediate-sector firm sets its price $p^x_t(\omega)$ to maximize its period profit $d_t(\omega) = (p^x_t(\omega) - A^{-1})x_t(\omega)$ subject to production sector demand $p^x_t(\omega) = p^F_t\xi(F_t/X_t)x_t(\omega)^{\frac{1-\nu}{\nu}}$. In a symmetric equilibrium the optimal price is $p^x_t = \nu\, A^{-1}$ and quantity of the intermediate good, as well as firms' profit are the following:

$$x_t = \left(\frac{A\xi}{\nu}\right)^{\frac{1}{1-\xi}} (p^F_t Z_t)^{\frac{1}{1-\xi}} N_t^{\frac{\nu\xi-1}{1-\xi}} \tilde{K}^\alpha_t L^{1-\alpha}_t \tag{21}$$

$$d_t = \frac{\nu-1}{\nu}p^x_t x_t = \frac{\nu-1}{A}x_t \tag{22}$$

Positive profit in this sector motivates entry. To open a firm, an entrepreneur needs to pay an sunk entry cost that consists of the cost of buying a blueprint of a new product from innovators at a price p^b_t. New firms finance entry by selling shares of their equity to entrepreneurs. Free entry pins down the equilibrium value of an intermediate firm, which should be equal to the entry cost: $v_t = p^b_t$.

3.2.3 *Wholesalers*

Each monopolistically competitive wholesale firm $j \in (0,1)$ purchases homogeneous production-sector good F_t at the price P_t^F and transforms it into a differentiated variety sold to retailers one-to-one $Y_t(j) = F_t(j)$. Following Rotemberg (1982), wholesale-good prices are sticky due to the presence of a quadratic price adjustment cost $AC_{p,t} = \frac{\psi_p}{2}\left(\frac{P_t(j)}{P_{t-1}(j)\Pi} - 1\right)^2 Y_t$, where parameter $\psi_p \geq 0$ governs the strength of nominal rigidity and Π is the steady-state inflation rate.

Each wholesaler sets the price $P_t(j)$ to maximize the future expected profit stream $d_t^w(j)$, subject to retailers demand:

$$\max_{\{P(j)_{t+k}\}_{k=0}^{\infty}} \quad \mathbb{E}_t \sum_{k=0}^{\infty} \Lambda_{t,t+k}^B d_t^w(j) = \mathbb{E}_t \sum_{k=0}^{\infty} \Lambda_{t,t+k}^B \left[\frac{P_{t+k}(j)}{P_t} Y_{t+k}(j) - \frac{P_{t+k}^F}{P_t} F_{t+k}(j) - AC_{p,k}(j) - \Gamma\right], \quad \text{s.t}$$

$$Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\eta} Y_t$$

The problem implies that the optimal price $P_t(j)$ is a time-varying markup over the marginal cost $P_t(j) = \mu_t P_t^F$, where the markup is:

$$\mu_t = \frac{\eta}{(\eta-1) + \psi_p \frac{\Pi_t}{\Pi}\left(\frac{\Pi_t}{\Pi} - 1\right) - \psi_p \, \mathbb{E}_t \, \Lambda_{t,t+1}^B \left(\frac{\Pi_{t+1}}{\Pi} - 1\right) \frac{\Pi_{t+1}}{\Pi} \frac{Y_{t+1}}{Y_t}} \tag{23}$$

When prices are flexible, $\psi_p = 0$, the markup is constant over the business cycle $\mu = \frac{\eta}{\eta-1}$. Given the optimal price choice, the real period profit of a wholesaler j is $d_t^w(j) = \left(1 - \frac{1}{\mu_t}\right) Y_t(j) - AC_{p,t}(j) - \Gamma$. To ensure zero steady state profit in this sector and rule out entry, I assume that production involves a fixed cost $\Gamma = \frac{1}{\eta} Y$.

3.2.4 *Retailers*

Firms in the retail sector are perfectly competitive and demand varieties of the wholesale good $Y_t(j)$ to produce the final consumption-investment good. The final good is a CES aggregate of wholesale varieties $Y_t = \left(\int_0^1 Y_t(j)^{\frac{\eta-1}{\eta}} dj\right)^{\frac{\eta}{\eta-1}}$. The corresponding aggregate price index and demands are standard: $P_t = \left(\int_0^1 P_t(j)^{\frac{1}{1-\eta}} dj\right)^{1-\eta}$ and $Y_t^d(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\eta} Y_t$.

3.2.5 *Innovators*

The sector of innovators involves inventing blueprints for new types of intermediate goods. The sector is populated with the unbounded mass of potential innovators. Let S_t be the total innovation spending and ϕ_t^i be the innovators' individual productivity parameter. The individual production function blueprints of intermediate goods is then $N_{et}^i = \phi_t^i S_t^i$.

In aggregate, however, the technology coefficient ϕ_t depends on the existing stock of knowledge, measured by the number of existing intermediate goods, N_t. As in Romer (1990), this knowledge spillover externality is responsible for the existence of the balanced growth path in the model. Moreover, in line with Comin and Gertler (2006), I include congestion externally $N_t^{\rho} S_t^{1-\rho}$ that allows to control for the aggregate elasticity of blueprints output with respect to innovation spending. The resulting aggregate innovators productivity is:

$$\phi_t = \phi \frac{N_t}{N_t^{\rho} S_t^{1-\rho}}, \tag{24}$$

where $S_t = \int_i S_t^i di$. The aggregate production function of innovators is then $N_{et} = \phi N_t \left(\frac{S_t}{N_t}\right)^{\rho}$. Investors maximize their expected profit stream subject to a quadratic adjustment costs in innovation spending:

$$\max_{\{S_{t+j}^i\}_{j=0}^{\infty}} \quad \mathbb{E}_t \sum_{j=0}^{\infty} \Lambda_{t,t+j}^B \left(p_{t+j}^b \phi_{t+j} S_{t+j}^i - (1 + AC_{S,t+j}) S_{t+j}^i\right)$$

The first-order condition is:

$$\phi_t p_t^b = 1 + AC_{S,t} + AC'_{S,t} S_t^i - \mathbb{E}_t \left(\Lambda_{t,t+1}^B AC'_{S,t+1} S_{t+1}^i\right) \tag{25}$$

I assume the standard quadratic adjustment cost $AC_{S,t} = \frac{\psi_S}{2}\left(\frac{S_t^i}{S_{t-1}^i g} - 1\right)^2$, where g is the growth rate of the economy on the balanced growth path.

As in Bilbiie et al. (2012), I there is a time-to-build lag: newly invented blueprints are adopted with a one-period lag.[24] At each period existing varieties of the intermediate good face a constant probability of becoming obsolete δ_N. The resulting law of motion for the total number of intermediate-good varieties is $N_{t+1} = (1 - \delta_N)(N_t + N_{et})$, where $N_{et} = \int_i N_{et}^i di$.

The positive knowledge spillover externality in the innovation sector gives rise to variety-

[24] I abstract from endogenous adoption of technologies as in Comin and Gertler (2006), Anzoategui et al. (2019), and Correa-López and de Blas (2018), among others. The inclusion of this feature would allow to capture the cyclicality of adoption, but would not alter the main conclusions.

driven endogenous growth, which rate equals to:

$$g_{t+1} = \frac{N_{t+1}}{N_t} = (1-\delta_N)\left(1+\phi\left(\frac{S_t}{N_t}\right)^{\rho}\right) \tag{26}$$

The endogenous growth rate g_t varies over the business cycle depending on the level of innovation spending S_t, which is determined in general equilibrium.

3.3 Monetary policy

Monetary policy is conducted through interest rate setting. The policy rate r_t is governed by a Taylor rule that allows for an occasionally binding zero lower bound constraint:

$$1+r_t = \max\left[0;(1+r_{t-1})^{\rho_r}\left((1+r)\left(\frac{GDP_t}{GDP_t^{BGP}}\right)^{\phi_Y}\left(\frac{\Pi_t}{\Pi}\right)^{\phi_\Pi}\right)^{1-\rho_r}\tilde{r}_t\right] \tag{27}$$

Parameters $\phi_Y \geq 0$ and $\phi_\Pi > 0$ govern the policy response to changes in GDP and inflation; $\rho_r \in [0,1)$ determines the degree of interest rate smoothing; $\tilde{r}_t$ it an exogenous disturbance to the policy rate. Note that the above rule responds to changes in the domestic GDP relative to its balanced growth path. In other words, the monetary authority does not respond to endogenous changes in the productivity growth, which is consistent with how central banks tend to conduct monetary policy.

3.4 Symmetric equilibrium

In a symmetric equilibrium all retailers are alike, so $P_t(j) = P_t$ and $Y_t(j) = Y_t = F_t$, $\forall j$, and the relative price of the production-sector is the inverse of the wholesale markup $p_t^F = \frac{1}{\mu_t}$. Similarly, a representative borrower owns all intermediate firms $\iota_{t+1} = \iota_t = 1$, each of which is alike $x_t(\omega) = x_t$, $p_t^x(\omega) = p_t^x$, $d_t(\omega) = d_t$, $\forall\omega$.

Since some output is used by the intermediate sector, the correct measure of real GDP in the model economy is the retail-sector output net intermediate consumption. Real GDP then equals to the sum of the total consumption, capital investment, firm creation spending (sunk entry cost), and the total adjustment cost spending:

$$GDP_t = Y_t - N_t\frac{x_t}{A} = C_t^S + C_t^B + I_t + e_tN_{e,t} + AC_{p,t} + AC_{S,t} + AC_{I,t}$$

Equilibrium choices of intermediate producers along with other optimality conditions allow to express the production-sector output as follows:

$$Y_t = N_t^{\frac{\xi(\nu-1)}{1-\xi}} \left(\frac{A\xi}{\nu}\right)^{\frac{\xi}{1-\xi}} Z_t^{\frac{1}{1-\xi}} \mu_t^{\frac{\xi}{\xi-1}} \tilde{K}_t^{\alpha} L_t^{1-\alpha} \tag{28}$$

This expression makes it clear that the following condition on structural parameters needs to be satisfied for growth to take a labor-augmenting form: $\frac{\xi(\nu-1)}{1-\xi} = 1-\alpha$. In this case, real GDP in the model economy simplifies to $Y_t^{GDP} = \Omega_t Z_t^{\frac{1}{1-\xi}} \tilde{K}_t^{\alpha}(N_t L_t)^{1-\alpha}$, where $\Omega_t = \left(\frac{A\xi}{\nu\mu_t}\right)^{\frac{\xi}{1-\xi}} - \left(\frac{A\xi}{\nu\mu_t}\right)^{\frac{1}{1-\xi}}$. Now, define the Solow residual as $TPF_t = Y_t^{GDP}/(K_t^{\alpha} L_t^{1-\alpha})$. The following model-consistent output decomposition then holds true (expressed in log differences):

$$\Delta Y_t^{GDP} = \Delta TPF_t + \alpha \Delta K_t + (1-\alpha)\Delta L_t$$

$$\Delta TPF_t = \underbrace{\Delta\Omega_t}_{\text{Markup effect}} + \underbrace{\alpha\Delta u_t}_{\text{Utilization effect}} + \underbrace{(1-\xi)^{-1}\Delta Z_t}_{\text{Exogenous TFP}} + \underbrace{(1-\alpha)\Delta N_t}_{\text{Innovation effect}}$$

The measured TFP in the model is driven by four components. The first one relates to the fact that the wholesale-sector markup distorts the quantity of the intermediate good produced; the second component is the short-run variations in the measured TFP due to time-varying capital utilization; the third is the exogenous TFP component subject to stationary shocks. These three terms drive stationary fluctuations in the measured TFP. The last term is the *innovation effect* stemming from accumulation of the stock of intermediate goods, which drives fluctuations in the trend growth.

Finally, the credit, housing, and labor markets clear:

$$B^B + B^S = 0 \tag{29}$$

$$h_t^B + h_t^S = 1 \tag{30}$$

$$L_t^B + L_t^S = L_t \tag{31}$$

Equilibrium definition: equations (4-32) determine 29 endogenous variables ($y_t, c_t^B, c_t^S, b_{t+1}^B, b_{t+1}^S, \chi_t, x_t, L_t^S, L_t^B, L_t, \upsilon_t, w_t, R_t^K, k_{t+1}, i_t, q_t, \Pi_t, \mu_t, r_t, h_t^B, h_t^S, p_t^h, v_t, s_t, \phi_t, d_t, g_{t+1}, u_t, \delta_{K,t}$) as a function of endogenous states ($b_t^B, b_t^S, \upsilon_{t-1}, k_t, i_{t-1}, r_{t-1}, h_{t-1}^B, h_{t-1}^S, s_{t-1}, g_t$) and exogenous states ($\vartheta_t, Z_t, \tilde{r}_t$). Table 3 lists all equilibrium conditions of the model expressed in terms of stationary lower-case variables that remain constant on the balanced growth path, e.g. $y_t = \frac{Y_t}{N_t}$, $i_t = \frac{I_t}{N_t}$, and $c^B = \frac{C_t^B}{N_t}$.

4 Model analysis

4.1 Parameter values and estimation

4.1.1 Calibrated parameters

The model is calibrated at quarterly frequency. To the extent possible, the parameter choice is informed either directly by the data or by the existing estimates in the literature.

I first describe the structural parameters of the household sector. I set the relative risk aversion to $\sigma = 2$, as common in the literature. I calibrate innovators productivity ϕ to match the 0.8% annual TFP growth rate on the BGP, an average across countries in the empirical exercise, i.e. $g = 1.008^{1/4}$. The steady-state real interest rate is then pinned down by the savers discount rate as follows: $R = \frac{1+r}{\Pi} = \frac{g^{\sigma}}{\beta^{S}}$. I chose β^S to replicate the steady-state annual real interest rate of 4%, which implies $\beta^S = 0.9968$. The borrowers discount factor should be lower than the savers discount factor. Under this assumption, the collateral constraint binds in the deterministic steady state as impatient households choose to borrow as much as possible. The difference between the two discount factors determines the steady-state shadow value of the borrowing constraint as follows: $\chi = \frac{\beta^S - \beta_B}{\beta^S}\left(1 - \frac{\rho_B \beta_B}{\Pi g^{\sigma}}\right)$; it also determines how often the collateral constraint binds over the business cycle. I choose $\beta^B = 0.9963$ so that the borrowers are only slightly more impatient than savers and hence become credit-constrained only occasionally.

I assume the Frisch elasticity of labor supply of $\frac{1}{\epsilon_L} = 4$, consistent with the King and Rebelo (1999) calibration. The price elasticity of housing demand choice is based on the results from Hanushek and Quigley (1980) who provide estimates of this elasticity in the range of -0.2 to -0.9 in the long-run and around -0.1 in the short-run (within a year) . Given my focus on short- and medium-run fluctuations I assume relatively inelastic demand and set $\epsilon_h = 5$. Calibration of the following two parameters relies on the estimates from Warnock and Warnock (2008). I set the loan-to-value ratio (LTV henceforth) to $m = 0.75$, which is close to an average LTV ratio across European countries. The steady-state weight of housing in the utility function κ is calibrated to set the steady-state mortgage debt-to-GDP ratio to 55%, an average for 23 developed countries over 2001-2005.

I now turn to the structural parameters of the production side of the economy. The capital share is set to the average value across the sample of studied events $\alpha = 0.4$ (Penn World Table v. 9.1 estimates). The share of intermediate goods is set to $\xi = 0.5$, consistent with the existing literature. I set the elasticity of substitution between intermediate inputs then is pinned down by the BGP requirement $\frac{\xi(\nu-1)}{1-\xi} = 1 - \alpha$, which implies $\nu = 1.6$, as in Comin and Gertler (2006) who motivate the low value of this parameter by the specialized nature of intermediate products. Next, I set the elasticity of substitution between varieties of the final investment-consumption good to $\eta = 11$ implying a steady-state markup of 10%, a conventional choice in the literature. Based on equivalence results of Born and Pfeifer (2016), the quadratic price adjustment cost parameter is set to $\psi_p = 120$ to replicate, in a linearized setting, the slope of the Phillips curve derived using Calvo stickiness with an average price duration of about a year, which is close to direct estimates of Galí and Gertler (1999).

To normalize the steady-state capital utilization to 1, I set $c_1 = \frac{\beta_S}{\beta_B} R - 1 - \delta_K$. I set the value of quarterly capital depreciation standard in the literature $\delta_K = 0.025$. Following Bilbiie et al. (2012), I set the intermediate firm exit rate $\delta_N = 0.025$. This value is based on the Bernard et al. (2010) estimate of the minimum production destruction rate, measured as a market share. It is also consistent with the Caballero and Jaffe (1993) estimate of technological obsolescence rate. As in Comin and Gertler (2006), the elasticity of innovators output to expenditure is set to $\rho = 0.8$. The steady-state aggregate productivity level Z is chosen to normalize the steady-state GDP to unity. Finally, I assume 2% steady-state annual inflation, and choose the following parameters of the Taylor rule: $\phi_Y = 0.5/4$, $\phi_\pi = 1.5$, $\rho_r = 0.7$, as common in the literature Table 4 summarizes parameters of the baseline model.

4.1.2 Shock process and the solution method

I use the structural model described in the previous section to explore the mechanism and draw policy implications of a negative shock to housing prices. This scenario is simulated as a result of a negative housing preference (demand) shock ε_t^ϑ that affects the housing preference parameter governed by a standard AR(1) process $\ln(\vartheta_t) = (1 - \rho_\vartheta)\ln(\vartheta) + \rho_\vartheta \ln(\vartheta_{t-1}) + \varepsilon_t^\vartheta$. I resort to this shock as an exogenous disturbance to the house price based on the evidence from the existing literature. In particular, Liu et al. (2013) identify this shock as the one that drives most of the fluctuations in the U.S. land prices and is crucial for generating the empirical comovement between land prices and investment. Later estimates of Guerrieri and Iacoviello (2017) suggest that about 70% of the consumption decline during the Great Recession in the U.S. can be traced back to housing demand shocks.[25] This shock should be treated as reflecting not only pure changes in the taste for housing but also other unmodeled factors that shift housing demand. In the context of housing market crashes the former can be interpreted as a

[25] See also the study of sources and consequences of US housing market fluctuations in Iacoviello and Neri (2010).

sudden realization that the explosive housing market dynamics is unsustainable and the asset is overvalued, akin to the work of Minsky (1986) that got back in vogue since the Global Financial Crisis. Other factors central for housing demand and about which the model is silent include mortgage credit availability.

The model features two sources of non-linearities: the zero lower bound constraint on the policy rate and the collateral constraint. The presence of these two occasionally binding constraint (OBC henceforth) poses a computational difficulty since the model cannot be solved using standard perturbation methods. One way to tackle this issue is to resort to policy/value function iteration or other global solution methods that allow to fully account for the non-linearities and precautionary behavior linked to the possibility that the constraint may become binding in the future. However, these methods are computationally demanding and are not easily scalable due to the curse of dimensionality. The simplest alternative solution was introduced by Guerrieri and Iacoviello (2015) and involves using a piecewise-linear solution. This method builds on the insight that occasionally binding constraints can be handled as different regimes of the same model. Under one regime, the occasionally binding constraint is slack. Under the other regime, the same constraint is binding. The piecewise linear solution method involves linking the first-order approximation of the model around the same point under each regime. However, just like any linear solution, this method does not allow to capture the effects of uncertainty and so to account for precautionary behavior. I use a similar approach developed by Holden (2019) and implemented as an extension to Dynare: DynareOBC.[26] Unlike the Guerrieri and Iacoviello (2015) method, its compatible with higher-order approximations and by integrating over future uncertainty allows to capture some of the precautionary behavior.

4.1.3 Estimated parameters

I first investigate the ability the model to account for the macroeconomic dynamics associated with housing market crashes documented in the event analysis of section 2.2. For that purpose, I conduct a "crisis" experiment by hitting the model economy with a series of negative housing preference shocks $\varepsilon_t^{\vartheta}$ calibrated to match the empirical dynamics of the aggregate housing price index. Autocorrelation of the shock process is set to 0.978, close to the estimate of Iacoviello and Neri (2010) who find housing preference shocks to be very persistent.

Given the sequence of negative housing demand shocks, I estimate the remaining five parameters of the model $P = \{\rho_b, \psi_N, \psi_K, \rho_\Upsilon, c_2\}$ to minimize the distance between empirical (local-

[26] Available at https://github.com/tholden/dynareOBC

projection) and theoretical (model-based) impulse responses, as in Christiano et al. (2005).[27] These are parameters that govern the borrowing limit inertia (ρ_b), innovation spending adjustment cost (ψ_N), investment adjustment cost (ψ_K), the disutility of labor inertia (ρ_Υ), and the responsiveness of capital depreciation to utilization (c_2). Before proceeding I want to emphasize that the overall quantitative predictions of the model are robust to the choice of the above parameters.

Formally, the problem is to minimize the weighted distance between the two IRFs:

$$\min_P \ (\Sigma^{DSGE}(P) - \Sigma^{LP}) \ \Omega^{-1} \ (\Sigma^{DSGE}(P) - \Sigma^{LP})',$$

where $\Sigma^{DSGE}(P)$ denotes the mapping between the estimated parameters of the model and the theoretical impulse responses; Σ^{LP} is a vector of empirical impulse responses; and Ω is the weighing matrix. As common in the literature, the weighting matrix includes standard deviations of the empirical impulse responses on the main diagonal, thus putting a larger weight on matching empirical impulse responses that are estimated with more precision. Since the model is calibrated at the quarterly frequency, I average theoretical impulse responses to make them comparable with empirical responses of annual frequency. I use empirical impulse responses of output, consumption, investment, capital, labor, and utilization-adjusted TFP for estimation. I exclude the IRF of the household debt-to-GDP ratio because of the problematic mapping between this variable in the model and the data. Firstly, this ratio in the data includes all household debt, not only mortgage debt. Moreover, it combines debt held by all households, not only those who do not hold enough liquid assets and are likely to become credit-constrained, the group I focus on in my analysis.

The estimation results in the following parameter values. The borrowing limit inertia $\rho_b = 0.67$, which is close to the estimate of Guerrieri and Iacoviello (2017); adjustment costs parameters for capital and innovation spending are $\psi_N = 0$ and $\psi_K = 2$ respectively. The low value of the capital utilization parameter $c_2 = 0.075$ suggests that this component of the model is important for capturing the short-run dynamics of the Solow residual. Finally, disutility of labor exhibits a significant degree of inertia, $\rho_\Upsilon = 0.98$, implying that in the short run the wealth effect in labor supply is weak.

[27] For the purpose of estimation I consider the sequence of shocks that hits the economy at the deterministic steady state at which the collateral constraint binds. In the later sections I explicitly explore the role of non-linearities induced by the occasionally binding collateral constant.

4.2 Accounting for the empirical evidence

Overall, the model accounts for the macroeconomic comovements during housing market crashes well. Immediate results of IRF matching are presented on panel (a) of figure 7. Two things are worth noting. First, the model predicts a somewhat weaker response of capital investment than in the data. The reason is straightforward: the theoretical framework abstracts from any amplification mechanisms that pertain capital accumulation directly. Second, the short-run response in labor is stronger than in the data. One possible reason being that the empirical response of labor is likely to be underestimated, since it does not account for changes in working hours.

Figure 8 shows a broader set of impulse responses associated with the IRF-matching experiment (baseline simulation henceforth). Given the perfectly inelastic housing supply, a sequence of negative demand shocks ϑ_t leads to a sharp decrease in the equilibrium house price. As a result, borrowers housing wealth falls reducing their borrowing capacity. Note that borrowers housing wealth falls by more than the house price. Although the housing preference shock is aggregate, in general equilibrium the housing stock is reallocated towards savers. This effect additionally contributes to the worsening of borrowers balance sheets, see section 5.3 for a detailed discussion.

When borrowers housing wealth falls and the collateral constraint binds, they are forced to reduce spending to meet the lower debt limit.[28] Under nominal rigidity, the reduction in spending leads to a demand-driven recession in the short run. Judging by the dynamics of debt and the borrowing constraint multiplier, the active phase of deleveraging lasts for about 20 quarters. However, it leaves a long-lasting scarring effect on the level of consumption and output due to its detrimental effect on the pace of innovation and capital accumulation. Panel (b) of figure 7 presents the decomposition of output and TFP dynamics. Consistent with the empirical evidence, the decline in the economic activity at medium-run horizons is driven largely by the negative effect on the level of capital stock and TFP. The model also allows to shed some light on the relative contributions of factors driving measured TFP. A significant part of a short-run response of the measured TFP, more than a half during the first year, is driven by a decrease in capital utilization and the markup distortion.

The shock is inflationary in the medium run. Although inflation is not significantly affected on impact, in about 8 quarters, as the acute phase of deleveraging is over, it persistently overshoots the steady-state level. Intuitively, this medium-run inflationary effect is driven by a

[28] In general, borrowers also deleverage by supplying more labor, but the assumption of GHH utility eliminates this effect.

persistent decrease in the capital stock and TFP, both of which push marginal costs up. The effect disappears if one shuts down the endogenous response of TFP and capital by setting the respective adjustment costs to arbitrary high values. Appendix C includes responses at various values of pre-existing household debt-to-GDP and loan-to-value (LTV) ratios.

5 Exploring the mechanism

I identify and illustrate four main channels that shape the general equilibrium response to negative housing demand shocks.

5.1 Aggregate demand channel

Under nominal rigidity borrowers deleveraging results in a demand-driven recession in the short run: the *aggregate demand channel*. When a negative housing preference shock causes the collateral constraint (9) to bind forcing borrowers to reduce spending to meet the lower credit limit. It might be tempting to think that the aggregate implications of this reduction in borrowing are of a second-order importance. After all, in a closed-economy context debt is money we owe to ourselves, so the implications of deleveraging may be mostly redistributional. However, the downward revision in the borrowing limit causes a temporary decrease in the natural rate, determined by the dynamics of the savers stochastic discount factor in the flexible price economy. Under nominal rigidity, the real interest rate may fail to adjust accordingly allow savers pick up most of the slack.

Doing away with nominal rigidity significantly reduces the real effect of the shock. Panel (a) of figure 9 compares the baseline simulation to the flexible-price counterfactual by setting the price adjustment cost to zero ($\psi_p = 0$). When prices are flexible, the real interest rate fully adjusts. As a result, consumption of savers increases on impact fully offsetting the fall in consumption of credit-constrained borrowers. The mild negative effect on the economy that remains is driven by supply-side factors. Even in a flexible-price economy, credit-constrained borrowers still decrease investment and innovation spending. The associated decrease in the marginal product of labor then lowers households labor supply.

Binding zero lower bound on the policy rate (ZLB henceforth) amplifies the effect of this channel by orders of magnitude. To illustrate it, I proceed as follows. I first append a risk-premium shock a_t to the savers intertemporal optimality condition (5): $\mathbb{E}_t\left(\Lambda^S_{t,t+1}\frac{1+r_t}{\Pi_{t+1}}\right) = 1+a_t$.

As common in the literature, I use this shock to simulate a situation when the ZBL binds.[29] A temporary increase in a_t reduces the natural rate and causes the policy rate to fall accordingly. I then calculate the effect of a baseline sequence of negative housing preference shocks contingent on the ZLB binding for the first 8 quarters.[30] Panel (b) of figure 9 presents the result. Binding ZLB significantly amplifies the effect of the shock. The amplification is driven by a larger decrease in the aggregate demand when the policy rate in constrained by the ZLB, which is reminiscent of the Eggertsson and Krugman (2012) discussion of the implications of household deleveraging under nominal rigidity and monetary policy constraints.

5.2 Productivity growth channel

The endogenous slowdown in productivity growth, the *productivity growth channel*, emerges as an additional margin of adjustment to the shock due to a combination of two forces. Forward-looking innovation spending falls as returns on this investment are temporary lower. Moreover, the consumption-smoothing motive of credit-constrained borrowers make them reduce investment by more than consumption when deleveraging. To facilitate illustration, throughout this section I abstract from adjustment costs in innovation spending by setting $\psi_N = 0$.

I first illustrate the contribution of this channel by shutting down endogenous fluctuations in TFP growth. Panel (a) of figure figure 10 compares the baseline simulation to the counterfactual where the endogenous growth mechanism is shut down by setting the innovation spending adjustment cost to an arbitrary high value ($\psi_S = 10^5$). As a result, consumption and output recover quickly and fully. Moreover, shutting down the endogenous growth mechanism lowers the medium-run inflationary effect of the shock. Finally, the on-impact effect of the shock is muted. This effect has to do with the fact that changes in expected income growth affect present consumption. I discuss this channel further in section 5.4.

What is the relative size of factors that cause a fall in productivity growth after a negative housing preference shock? Recall that entry of intermediate firms — and ultimately innovation spending — is financed by selling equity to households. To illustrate the equity market dynamics, I linearise the relevant equilibrium conditions to get the model-consistent linear eq-

[29] See Eggertsson et al. (2003), Eggertsson (2008), and Christiano et al. (2016), among others. This shock can be interpreted as a reduced-form way to capture the temporary increase in the agents desire to save. As Fisher (2015) has shown, it can also be interpreted as a structural shock to the demand for safe and liquid assets. To a first-order approximation, this shock is isomorphic to a savers discount factor shock.

[30] Formally, the effect of a shock conditional on binding ZLB is calculated as a difference between responses of variables in the following two simulations. (1) Baseline: a savers discount factor shock at $t = 0$ that causes the ZLB bind for a chosen number of periods. (2) Counterfactual: a savers discount factor shock at $t = 0$ that causes the ZLB bind for a chosen number of periods *and* a shock of interest at $t = 1$.

uity supply and demand curves. Please refer to appendix D.3 for derivations. The result is as follows:

$$\text{Equity supply: } \mathsf{v_t} = (1-\rho)\mathsf{s_t} \tag{32}$$

$$\text{Equity demand: } \mathsf{v_t} = \underbrace{\mathbb{E}_t\left(A_{v1}\mathsf{d_{t+1}} + A_{v2}\mathsf{v_{t+1}} - \mathsf{R_{t+1}}\right)}_{\text{Discounted next-period return}} - \underbrace{A^B_{\Lambda 1}\chi_\mathsf{t} + A^B_{\Lambda 2}\,\mathbb{E}_t(\chi_\mathsf{t+1} - \mathsf{R_{t+1}} - \Pi_\mathsf{t+1})}_{\text{Collateral constraint wedge}} \tag{33}$$

Given general equilibrium outcomes, these curves determine the current-period equity price $\mathsf{v_t}$ and the amount of innovation spending financed $\mathsf{s_t}$, in percentage deviations from the deterministic steady state. In the absence of innovation spending adjustment costs the supply curve does not shift. The equity demand shifts due to a combination of two factors. changes in returns from firm ownership, which consist of future expected stream of profit. Moreover, since these are borrowers who have an access to the equity market, their investment decisions are affected when they are credit-constrained ($\chi_t > 0$).

Panel (b) of figure figure 10 shows the equity market dynamics consistent with the simulation on the panel (a). As a result of a negative housing preference shock, the equity market equilibrium moves from the steady state at point A to an equilibrium with lower innovation spending as equity demand falls at $t = 5$ (point B). How much of this demand shift is directly due to the effect of binding collateral constraint vs the ? The dashed line plots the equity demand curve at $t = 5$ excluding, in a partial equilibrium sense, the effect of the collateral constraint wedge.

At this point of time, about two-thirds of the shift in the equity demand curve is directly driven by the collateral effect, the rest of it is driven by demand factors.

5.3 Fisherian debt deflation channel

Two more channels amplify the initial effect of the shock. First is the negative feedback loop between deleveraging and borrowers housing wealth: *Fisherian debt deflation*.[31] At the core of this channel is the *pecuniary externality*: credit-constrained borrowers do not internalize the effect of their individual spending reduction on aggregate housing wealth that ultimately affects their borrowing capacity. The initial deleveraging then exacerbates the damage to borrowers balance sheets and causes further deleveraging. I provide a glimpse into the strength of this

[31] Lately, this channel has been most widely discussed in the literature on emerging market crises, see for instance Mendoza (2010). However, it is standard for any model where the borrowing capacity is linked to the relative price of collateral, see the original discussion in Fisher (1933).

channel with two experiments.

Although the housing preference shock is aggregate, binding collateral constraint drives a sizable asymmetry in the dynamics of borrowers and savers housing demand. Similarly to the previous section, I use linearized equilibrium conditions to illustrate this point. Please refer to appendix D.2 for details. Let the san-serif font denote percentage deviations of variables from the deterministic steady state. The resulting linear housing demand curves are as follows:

$$\text{Savers demand: } \mathsf{p}^{\mathsf{h}}_{\mathsf{t}} = A^S_{h1}\mathsf{h}^{\mathsf{B}}_{\mathsf{t}} + A^S_{h2}\vartheta_{\mathsf{t}} - A^S_{h2}\tilde{\lambda}^{\mathsf{S}}_{\mathsf{t+1}} + A^S_{h3}\,\mathbb{E}_t\left(\mathsf{p}^{\mathsf{h}}_{\mathsf{t+1}} + \mathsf{g}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}}\right) \tag{34}$$

$$\text{Borrowers demand: } \mathsf{p}^{\mathsf{h}}_{\mathsf{t}} = -A^B_{h1}\mathsf{h}^{\mathsf{B}}_{\mathsf{t}} + \underbrace{A^B_{h2}\vartheta_{\mathsf{t}}}_{\text{Pref. shock}} - \underbrace{A^S_{h2}\tilde{\lambda}^{\mathsf{B}}_{\mathsf{t+1}}}_{\text{Wealth effect}} + \underbrace{A^B_{h3}\,\mathbb{E}_t\left(\mathsf{p}^{\mathsf{h}}_{\mathsf{t+1}} + \mathsf{g}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}}\right)}_{\text{Next-period discounted return}} \tag{35}$$

$$-\underbrace{A^B_{h4}\chi_{\mathsf{t}} + A^B_{h5}\,\mathbb{E}_t(\chi_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \Pi_{\mathsf{t+1}})}_{\text{Collateral constraint wedge}}$$

These model-consistent linear demand curves determine the aggregate real house price p^h_t and the allocation of housing towards borrowers $\mathsf{h}^{\mathsf{B}}_{\mathsf{t}}$ given the aggregate housing preference shock ϑ_{t} and general equilibrium outcomes (expressed in percentage deviations from the deterministic steady state). What causes these demand curves to shift? Common factors are the aggregate preference shock and changes in the expected next-period return. Demands are also affected by household-specific wealth effects: when the shadow value of consumption is high, the valuation of housing in consumption units is low and vice versa. Under the baseline particularization the wealth effect on the housing demand is small. Finally, the asymmetry between borrowers and savers housing demands is mainly driven by the effect of binding collateral constraint: the *collateral constraint wedge*. Simulations shows that for plausible parameter values the effect of this wedge on borrowers housing demand is negative: other things equal, binding collateral constraint causes borrowers to decrease their housing demand more than savers.

The negative equilibrium effect of binding collateral constraint on borrowers housing wealth is large and it significantly exacerbates deleveraging. Panel (b) of figure 11 plots the model-consistent demand curves implied by equations (34) and (35). The left panel shows the initial steady-state housing market equilibrium at $t = 0$ (point A). The middle panel presents a snapshot of the housing market equilibrium in the baseline simulation at $t = 5$. The shock pushes both demand curves down and causes the equilibrium price to sharply fall (point B). Importantly, the borrowers housing demand falls by more. As a result, borrowers housing wealth suffers not only because the house price falls, but also because the housing stock is being redistributed towards savers. The lion's share of this outcome is driven the collateral constraint wedge: the dashed line shows, in a partial equilibrium sense, the shift of borrowers demand curve excluding this effect (point C). The right panel plots the dynamics of borrowers and savers housing wealth in the baseline simulation.

Panel (a) of figure 11 shows the contrafactual dynamics of the economy where the effect of housing reallocation towards savers on the borrowing limit is shut down. In other words, equation (9) is modified as follows: $\frac{B^B_{t+1}}{P_t} \leq \rho_B m P^h_t \mathbf{h^B}$, where $\mathbf{h^B}$ is steady-state housing of borrowers. This exercise allows to mute some — but not all — of the effect of the Fisherian debt deflation channel. As the resulting impulse responses show, the reallocation of housing that arises endogenously as a result of borrowers deleveraging plays a quantitatively significant role in shaping the overall response of the economy.

5.4 Expected income growth channel

The second amplification force is the *expected income growth channel*: lower expected growth decreases current spending through intertemporal substitution. As such, the endogenous productivity growth mechanism is not only generates the persistent effect of deleveraging, but also amplifies the short-run response.[32]

To illustrate the driving forces of borrowers and savers consumption growth, I linearise their first-order conditions with respect to bond holdings, please refer to D.4 for details. Growth of marginal utility of consumption ($\mathbb{E}_t \, \mathsf{g}_{\lambda_{t+1}}$) is driven by the following factors:

$$\text{Savers: } \mathbb{E}_t \, \mathsf{g}_{\lambda^S_{t+1}} = \mathbb{E}_t \, \tilde{\lambda}^S_{t+1} - \tilde{\lambda}^S_t = -\mathbb{E}_t \, \mathsf{R}_{t+1} + \sigma \mathsf{g}_{t+1} \tag{36}$$

$$\text{Borrowers: } \mathbb{E}_t \, \mathsf{g}_{\lambda^B_{t+1}} = \mathbb{E}_t \, \tilde{\lambda}^B_{t+1} - \tilde{\lambda}^B_t = \underbrace{-\mathbb{E}_t \, \mathsf{R}_{t+1}}_{\substack{\text{Real interest}\\ \text{rate}}} + \underbrace{\sigma \mathsf{g}_{t+1}}_{\substack{\text{Productivity}\\ \text{growth}}} \underbrace{-A^B_{\Lambda 1} \chi_t + A^B_{\Lambda 2} \, \mathbb{E}_t (\chi_{t+1} - \mathsf{R}_{t+1} - \Pi_{t+1})}_{\text{Collateral constraint wedge}} \tag{37}$$

Note that productivity growth has a positive effect on the growth of marginal utility of consumption and the magnitude of this effect governed by the elasticity of intertemporal substitution. When growth is expected to be slower, consumption today decreases. As a result, the expected growth of the marginal utility of consumption increases. The above equations allow me to assess, in a partial equilibrium sense, the role productivity growth relative to other factors. For the interpretation of the results below, note that the model features GHH preference so the marginal utility of consumption also depends on labor.

Figure 12 plots the decomposition. In general equilibrium, the real interest rate falls, which, other else equal, has a positive impact on the growth of marginal utility of consumption.

[32] See also Benigno and Fornaro (2018) for the discussion of how the self-fulfilling negative feedback loop between the aggregate demand and expected growth can cause the economy to be stuck in a low-growth equilibrium.

However, for borrowers, the effect of binding collateral constraint, which works in the opposite direction, outweighs the real interest rate effect causing the marginal utility of consumption to fall. The decline in the marginal utility of consumption is then exacerbated by the expectation of slower next-period growth by more than twofold.

6 Policy scenarios

I conclude highlighting important implications for monetary and fiscal policy.

6.1 Monetary policy

Housing demand shocks — and more broadly shocks that manifest in deleveraging — warrant stronger focus of monetary policy on output stabilization. As section 5.1 illustrates, in the short run housing demand shocks propagate similarly to aggregate demand shocks. Naturally, their effects (at both short- and long-run horizons) are shaped by monetary policy. My question is of positive nature: I do not attempt to access optimal monetary policy. Rather, taking that the policy rate follows the Taylor rule as given, I want to access the sensitivity of the welfare cost of the baseline simulation to parameters of the rule. Please refer to appendix D.5 for the discussion of welfare calculations.

I simulate responses to a series of negative housing preference shocks as discussed in section 4.1.3 under various values of the policy rate response to inflation (ϕ_π) and cyclical variations of output (ϕ_Y). Moreover, I compare the results of the baseline model to the ones of the alternative where the endogenous growth mechanism is shut down by setting the R&D adjustment cost parameter to an arbitrary high value $\psi_N = 10^5$. Figure 13 illustrates the sensitivity of the welfare cost of the crisis to parameters of the Taylor rule. Three things stand out. First, in both cases the welfare cost of the shock is strictly decreasing in the strength of policy response to output. Stronger response to inflation, on the other hard, is not welfare-improving. Under certain combination of parameters it may even exacerbate the welfare loss. Second, the welfare cost of the crisis is often larger for savers than for borrowers, especially for the cases when the policy rate response to output is relatively weak. Finally, the endogenous growth mechanism magnifies the effect of the shock by as much as 5 times and further emphasizes the importance of output stabilization relative to inflation stabilization in the studied scenario.[33]

[33] This is broadly consistent with results of Garga and Singh (2020) and Ikeda and Kurozumi (2018) who study optimal monetary policy in business cycles models with endogenous growth.

6.2 Fiscal policy

How effective can fiscal policy be in mitigating the damage to borrowers balance sheets and resulting deleveraging due to a decline in house prices? I offer a glimpse into this question by studying the following policy. Suppose the government finances its expenditure G_t by levying lump-sum taxes of savers and borrowers, T_t^S and T_t^B respectively. The policy then involves shifting the tax burden from borrowers to savers by Δ_t. This can be interpreted as a debt relief program or, more generally, as a revenue-neutral tax reform that benefits borrowers. The government budget constraint and the modified budget constraints of savers and borrowers take the following form:

$$G_t = T_t^B + T_t^S \tag{38}$$

$$C_t^S + P_t^h(h_t^S - h_{t-1}^S) + (1 + r_{t-1})\frac{B_t^S}{P_t} = W_t L_t^S + \frac{B_{t+1}^S}{P_t} - (T_t^S + \Delta_t) \tag{39}$$

$$\begin{aligned} C_t^B + I_t + P_t^h(h_t^B - h_{t-1}^B) + (1 + r_{t-1})\frac{B_t^B}{P_t} + \iota_{t+1} v_t (N_t + N_{e,t}) = \\ \iota_t (v_t + d_t) N_t + W_t L_t^B + R_t^K u_t K_t + \frac{B_{t+1}^B}{P_t} + div_t - (T_t^S - \Delta_t) \end{aligned} \tag{40}$$

Debt relief measures implemented amid the crisis are very effective in alleviating both immediate and persistent effects of deleveraging.[34] Figure 14 presents baseline IRF-matching simulation along with the policy intervention counterfactual. The policy is a transfer Δ_t equivalent to a 0.25% of borrowers' steady-state debt burden. As in Guerrieri and Iacoviello (2017) the transfer is governed by an AR(1) process with a persistence coefficient equal to 0.5. The success of the policy is based on two factors. First, in the economy where borrowers are credit-constrained Ricardian equivalence no longer holds. Aa a result, a transfer towards borrowers is expansionary. Moreover, this policy strikes at the heart of amplification mechanisms that operate in the economy and are responsible for the lion's share of the resulting negative effect. The policy effectively alleviates the negative feedback loop between borrowers deleveraging, their housing wealth, and growth expectations (the *debt-deflation channel* and the *expected income channel*). Panel (b) shows the net effect on the policy and clearly indicates that the debt write-down relaxes the borrowers' credit constraint. As such, it offsets the immediate decrease in consumption and improves the medium-run trajectory of the economy by decreasing the decline in innovation and capital investment: the two components of the aggregate demand

[34] The result is consistent with empirical estimates of Auclert et al. (2019) who document the large and highly persistent effect of U.S. debt forgiveness measures on non-tradable employment. However, it is important to keep in mind that the ultimate effect of such measures depends on their pass-through to households. See Piskorski and Seru (2018) for the discussion of the role of housing market and housing finance rigidities.

that are affected by deleveraging the most.

7 Conclusion

Why recoveries from some recessions are particularly slow and incomplete? I contribute to this debate by studying the effects of housing market boom-and-bust cycles. First, using cross-country data, I explore the dynamics of recessions and recoveries associated with housing markets crashes. Such events are robustly associated a decline in consumption, output, and utilization-adjusted TFP that lasts longer than regular business-cycle fluctuations. Next, I built a dynamics general equilibrium model with borrower and saver households, occasionally binding collateral constraints tied to housing wealth, endogenous growth through forward-looking investment, and nominal rigidity to study the channels through which declines in house prices affect the macroeconomy. The model successfully accounts for the empirical comovements between variables; highlights the importance of endogenous innovation in generating persistent effect of the shock; and illustrates the key amplification mechanisms. I then use the model to study several policy scenarios. House price shocks that trigger delivering warrant stronger focus of monetary policy on output stabilization, and even more so in the presence of endogenous response in the productivity growth. Fiscal intervention that alleviates the debt burden of borrowers is effective in offsetting a large fraction of the shock when implemented during the crisis.

This paper opens a number of promising avenues for future research. The presented U.S. state-level and MSA-level evidence have illustrated the persistent regional divergence that can occur when member states are subject to asset market boom-and-bust cycles of different intensity. Thinking beyond the U.S. economy, a similar pattern has been even more vivid in the Eurozone in recent years. An interesting question then is how regional and supraregional policies can be designed and coordinated to alleviate this problem. A two-country open-economy extension of the theoretical framework of this paper would be suitable to explore this question. In terms of policy, the present work focused on a simple scenario of a transfer from savers to borrowers. A study of a broader set of more realistic fiscal policy measures, such as tax- and/or borrowing-financed increase in government spending, is warranted. I am working on the extensions to address these issues.

Figure 1: US real per capita GDP [cited on page 2 and 13]

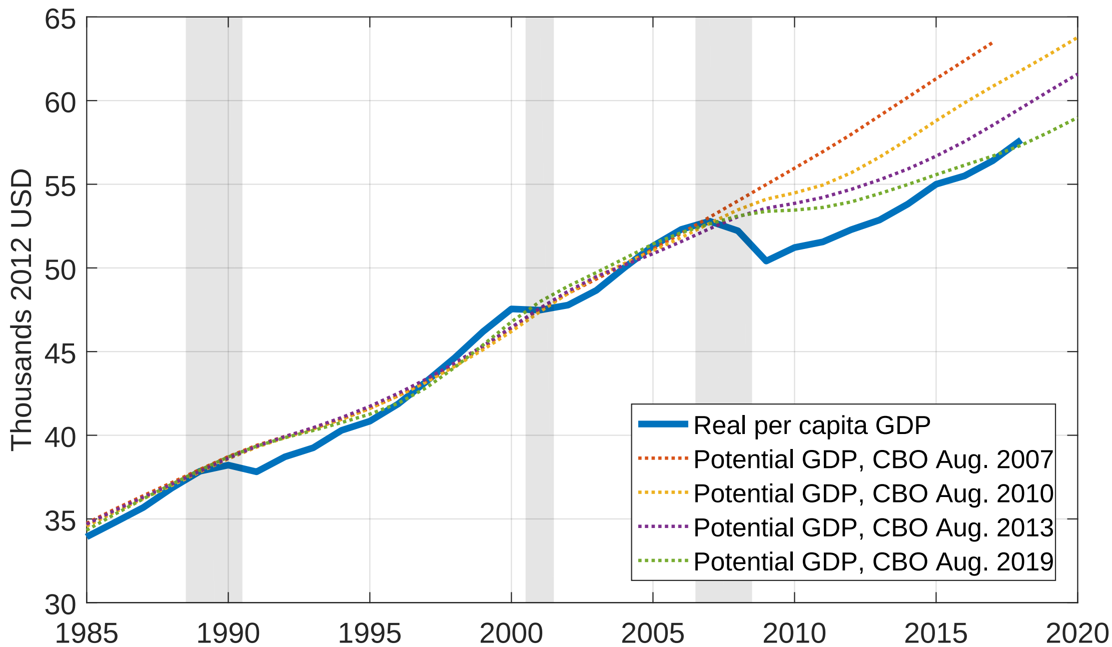


Figure 2: Housing market boom and bust cycles across countries [cited on page 2]

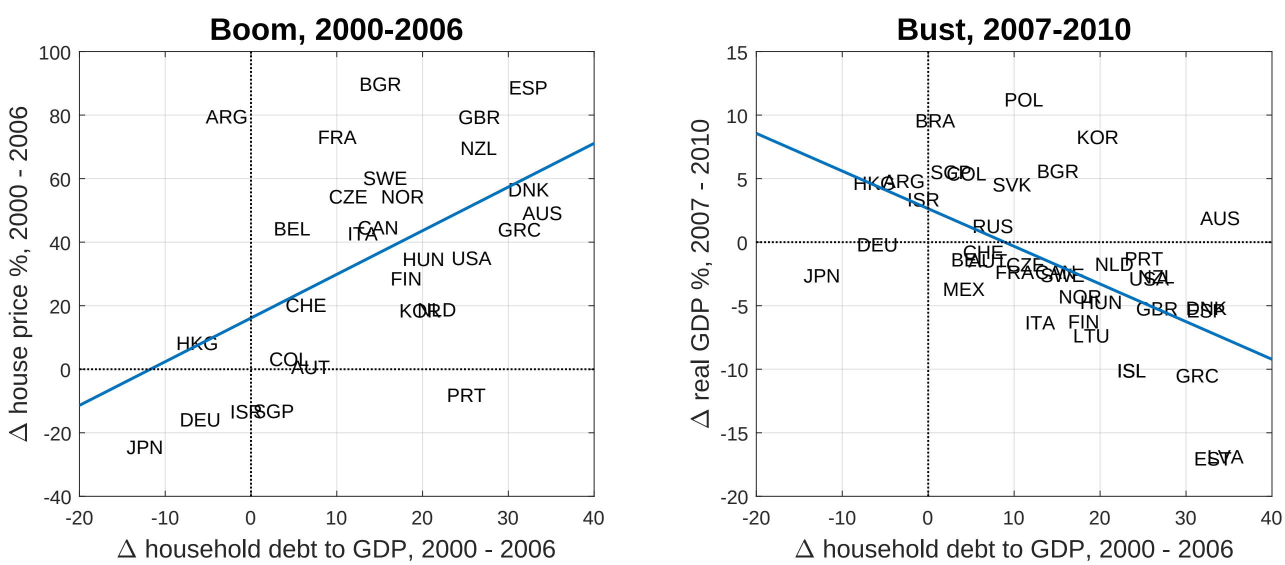
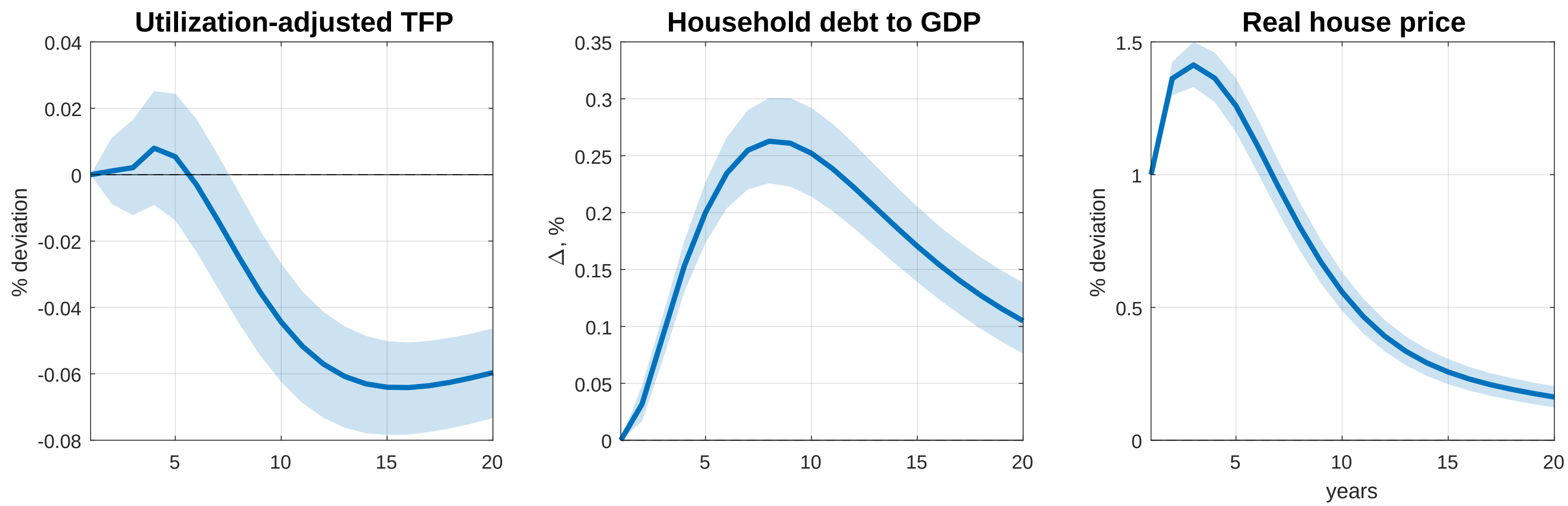


Figure 3: Panel VAR, responses to a house price shock [cited on page 9]



Note: cross-country panel VAR. House price shocks are identified with short-run restrictions with house price index ordered last. The system inclides 4 lags of variables based on the Akaike information criterion, as well as contry fixed effects.

Variables: (1) log utilization-adjsuted TFP index; (2) household debt-to-GDP; (3) log real house price index.

Shaded areas correspond to 95% confidence intervals obtained with bootstrap.

See details in section 2.1

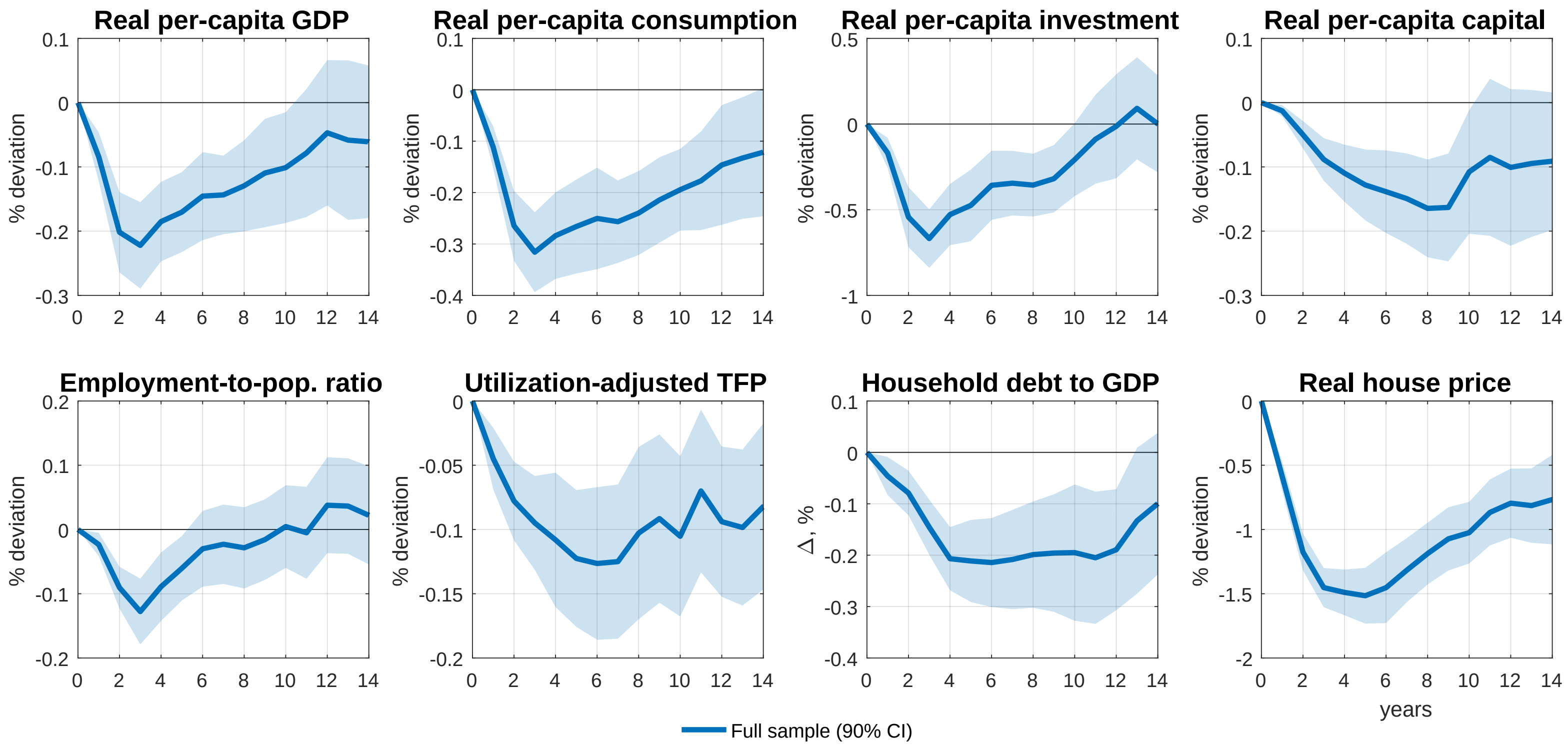
Table 1: Sample of housing market crashes [cited on page 10]

Country code	Peak	Trough	First 3 years	Peak to trough	Country code	Peak	Trough	First 3 years	Peak to trough
BEL	1979	1985	-26.4%	-37.5%	ITA	1981	1986	-21.1%	-31.5%
BGR	1996	2002	-39.9%	-51.5%	ITA	1992	1997	-14.3%	-25.6%
BGR	2008	2013	-39.1%	-43.8%	JPN	1974	1977	-23.3%	-23.3%
BRA	2014	2017	-15.6%	-15.6%	JPN	1991	2012	-13.2%	-50.8%
CAN	1981	1985	-26.3%	-30.0%	KOR	1991	1998	-24.9%	-42.7%
CHE	1973	1976	-19.7%	-19.7%	LTU	2007	2010	-42.7%	-42.7%
CHE	1990	2000	-20.0%	-32.9%	LUX	1980	1984	-22.2%	-23.1%
CHE	1959	1961	-12.4%	-12.4%	LVA	2007	2010	-47.0%	-47.0%
COL	1989	1992	-13.4%	-13.4%	MYS	1997	1999	-14.8%	-18.3%
COL	1995	2003	-14.4%	-35.0%	NLD	1964	1966	-27.2%	-28.6%
CZE	2008	2013	-15.4%	-19.1%	NLD	1978	1985	-34.0%	-48.2%
DEU	1981	1987	-11.3%	-14.3%	NLD	2008	2013	-11.5%	-26.0%
DNK	1979	1982	-33.6%	-33.6%	NOR	1987	1992	-28.9%	-43.1%
DNK	1986	1993	-18.4%	-31.5%	NZL	1974	1980	-18.4%	-35.5%
DNK	2007	2012	-19.4%	-28.0%	NZL	2007	2009	-11.4%	-11.4%
ESP	1991	1996	-13.3%	-15.0%	PER	1999	2003	-15.4%	-28.8%
ESP	2007	2014	-14.5%	-36.1%	PHL	1996	2004	-36.3%	-53.5%
EST	2007	2009	-51.0%	-51.8%	POL	2010	2013	-15.6%	-15.6%
FIN	1974	1979	-24.7%	-31.0%	PRT	1992	1996	-10.7%	-11.7%
FIN	1989	1993	-42.2%	-47.5%	RUS	2008	2011	-33.0%	-33.0%
FRA	1980	1985	-11.3%	-16.4%	SGP	1983	1986	-31.4%	-31.4%
GBR	1973	1977	-23.5%	-28.9%	SGP	1996	1998	-32.2%	-33.9%
GBR	1989	1996	-21.9%	-30.0%	SRB	2010	2013	-29.4%	-29.4%
GBR	2007	2012	-16.0%	-23.0%	SVK	2008	2012	-21.4%	-26.1%
GRC	2007	2017	-15.1%	-44.8%	SVN	2011	2014	-20.6%	-20.6%
HKG	1981	1984	-46.8%	-46.8%	SWE	1979	1985	-26.3%	-34.8%
HKG	1997	2003	-42.2%	-57.3%	SWE	1990	1993	-30.4%	-30.4%
HRV	1999	2002	-14.3%	-14.3%	THA	2006	2009	-30.1%	-30.1%
HRV	2009	2015	-18.6%	-24.0%	USA	2006	2012	-14.2%	-25.8%
HUN	2006	2013	-16.7%	-36.7%	ZAF	1984	1987	-39.4%	-39.4%
IRL	2006	2012	-30.4%	-46.1%	ZAF	2007	2012	-16.1%	-19.1%
ISL	2007	2010	-32.3%	-32.3%	Median	5 years		-21.1%	-30.6%

Note: unbalanced panel of 50 countries, 1950-2017. Housing market boom-and-bust cycles are identified in 43 countries. The sample consists 63 events: 39 before 2006 and 24 during/after the GFC.

Housing market bubbles are defined as periods when the aggregate housing price index (1) deviates from the long-run trend by more than one standard deviation and (2) declines of at least 10% within the first three years from the peak.

Figure 4: Event study, comovements during housing market crashes [cited on page 11]



Note: cross-country panel estimation, controlling for country and year fixed effects, country-specific trends, and preexisting macroeconomic conditions.

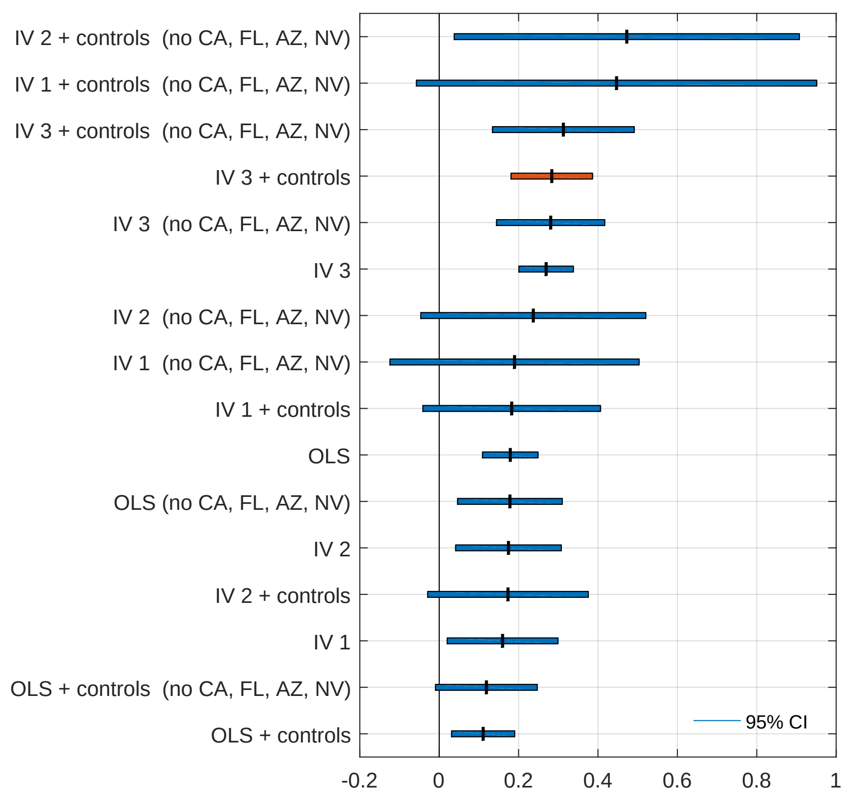
Responses are estimated by local projections and are expressed in log deviations times 100. Shaded areas correspond to 90% confidence intervals. Standard errors are clustered at the country level.

See details in section 2.2

Figure 5: 2007 US housing market crash [cited on page 13]

(a) Labor productivity growth and the house price decline

(b) Elasticity of labor productivity growth to the house price decline



Note: Baseline specification is in red, see details in table 2.

Table 2: Elasticity of 2007-2017 labor productivity growth to the house price decline

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ house price 2007-2010	0.18***	0.16**	0.17**	0.27***	0.18***	0.19	0.24	0.28***
	(0.04)	(0.07)	(0.07)	(0.03)	(0.07)	(0.16)	(0.14)	(0.07)
Constant	0.05***	0.05***	0.05***	0.06***	0.05***	0.05***	0.05***	0.06***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Observations	383	250	250	380	325	209	209	322
Specification	OLS	IV1	IV2	IV3	OLS	IV1	IV2	IV3
Controls								
Excluding CA, FL, NV, AZ					+	+	+	+

	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Δ house price 2007-2010	0.12***	0.13	0.13	0.28***	0.14**	0.29	0.32*	0.32***
	(0.04)	(0.10)	(0.09)	(0.05)	(0.06)	(0.22)	(0.18)	(0.09)
GDP construction share, 2006	-0.77**	-0.93*	-0.91*	-0.23	-0.03	0.56	0.60	0.42
	(0.34)	(0.56)	(0.52)	(0.38)	(0.43)	(0.71)	(0.68)	(0.46)
Constant	0.06	-0.02	-0.02	0.05	0.08	-0.09	-0.10	0.05
	(0.06)	(0.10)	(0.10)	(0.06)	(0.07)	(0.12)	(0.13)	(0.07)
Observations	312	200	200	310	257	160	160	255
Specification	OLS	IV1	IV2	IV3	OLS	IV1	IV2	IV3
Controls	+	+	+	+	+	+	+	+
Excluding CA, FL, NV, AZ					+	+	+	+

Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: labor productivity is defined as real GDP per worker. State and MSA output and employment data is from BEA. House price growth is based on FHFA all-transactions house price indexes. Controls: 2006 shares in GDP of (a) mining, quarrying, and oil and gas extraction; (b) construction; (c) manufacturing; (d) retail trade; as well as (e) 2006 per capital personal income. Reduced sample explides four states that were affected by the housing market crash the most.

IV 1: Saiz (2010) housing supply elasticity instrument, linear first stage; IV 2: Saiz (2010) housing supply elasticity instrument, quadratic first stage; IV 3: Guren et al. (2018) regional sensitivity instrument. See details in section 2.3.

Figure 6: Baseline model flow chart [cited on page 14]

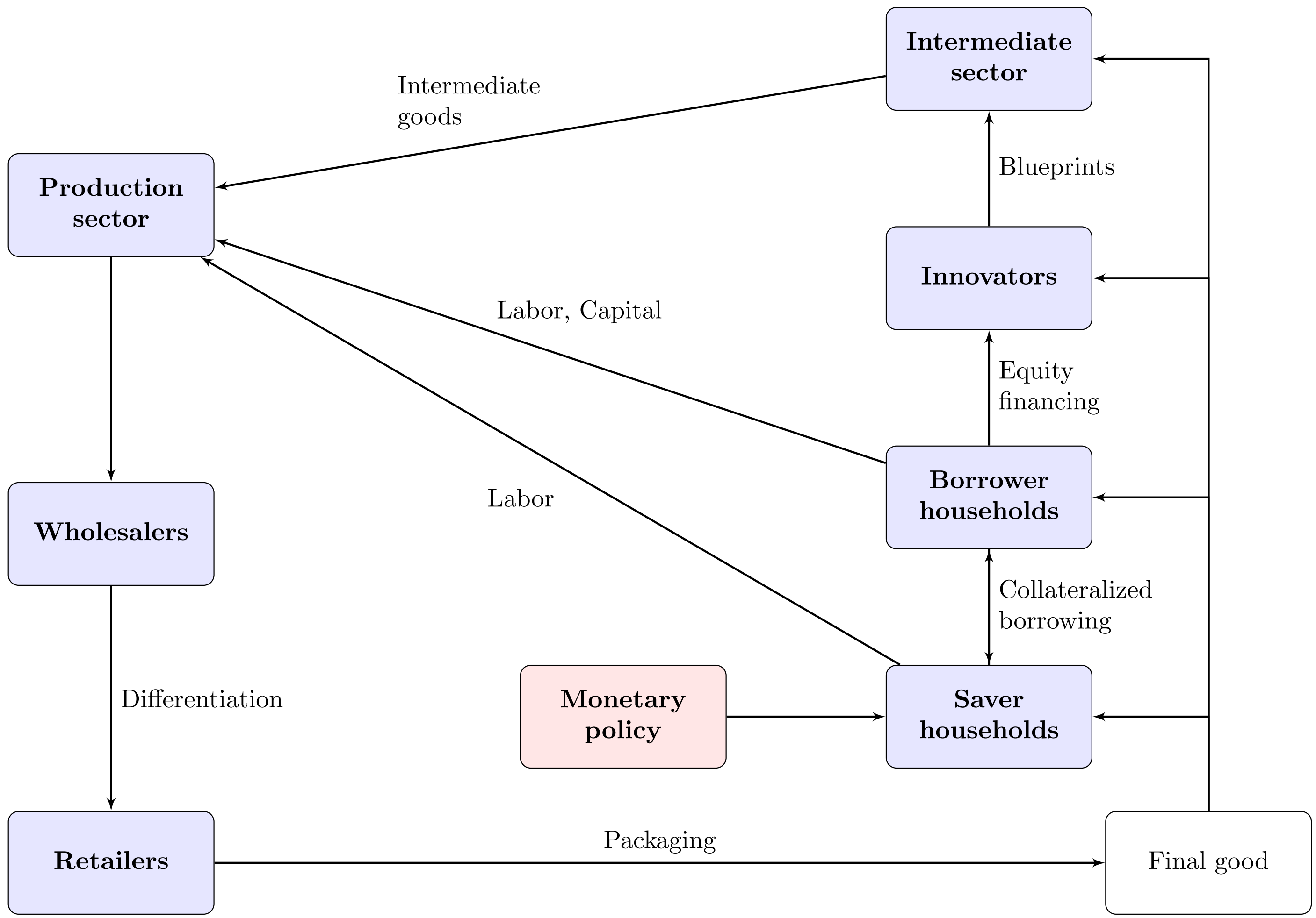


Table 3: Model summary [cited on page 23]

1. Final good market clearing	$y_t - \frac{x_t}{A} = c_t^S + c_t^B + i_t + p_t^b n_{e,t} + AC_{S,t} + AC_{p,t} + AC_{I,t}$
2. Savers budget constraint	$c_t^S + p_t^h(h_t^S - h_{t-1}^S) + \frac{1+r_{t-1}}{\Pi_t}\frac{b_t^S}{g_t} = w_t L_t^S + b_{t+1}^S$
3. Intermediate good output	$x_t = \left(\frac{A\xi}{\nu}\frac{Z_t}{\mu_t}\right)^{\frac{1}{1-\xi}} \tilde{k}_t^{\alpha} L_t^{1-\alpha}$
4-5. Savers/borrowers bond demand	$\mathbb{E}_t\left(\Lambda_{t,t+1}^S \frac{1+r_t}{\Pi_{t+1}}\right) = 1, \quad \mathbb{E}_t\left(\Lambda_{t,t+1}^B \frac{1+r_t-\rho_B\chi_{t+1}}{\Pi_{t+1}}\right) = 1-\chi_t$
6. Collateral constraint	$(b_{t+1}^B - \rho_B\frac{b_t^B}{\Pi_t g_t} - (1-\rho_B)mp_t^h h_t^I)\chi_t = 0, \quad \chi_t \geq 0$
7. Credit market clearing	$b_t^B + b_t^S = 0$
8-9. Savers/borrowers labor supply	$w_t = \upsilon_t (L_t^H)^{\epsilon}, \quad H \in \{S, B\}$
10. Disutility of labor	$\upsilon_t = (\upsilon_{t-1}/g_t)^{\rho_\Upsilon}$
11. Labor demand	$w_t = \frac{1}{\mu_t}(1-\alpha)(1-\xi)\frac{y_t}{L_t}$
12. Labor market clearing	$L_t = L_t^B + L_t^S$
13. Capital supply	$q_t = \mathbb{E}_t\left(\Lambda_{t,t+1}^B((1-\delta_{K,t})q_{t+1} + R_{t+1}^K)\right)$
14. Tobin's q	$q_t = 1 + q_t(AC_{I,t} + AC'_{I,t} i_t) - \mathbb{E}_t\left(\Lambda_{t,t+1}^B q_{t+1} AC'_{I,t+1} i_{t+1}\right)$
15. Capital law of motion	$k_{t+1}g_{t+1} = (1-\delta_{K,t})k_t + (1-AC_{I,t})i_t$
16-17. Capital utilization	$R_t^K = c_1 + c_2(u_t - 1), \quad \delta_{K,t} = \delta_K + c_1(u_t-1) + \frac{c_2}{2}(u_t-1)^2$
18. Capital demand	$R_t^K = \frac{1}{\mu_t}\alpha(1-\xi)\frac{y_t}{\tilde{k}_t}$
19. Savers housing demand	$p_t^h = \mathbb{E}_t\left(\Lambda_{t,t+1}^S p_{t+1}^h g_{t+1}\right) + \kappa\vartheta_t \frac{(h_t^S)^{\epsilon_h}}{\tilde{\lambda}_t^S}$
20. Borrowers housing demand	$p_t^h = \mathbb{E}_t\left(\Lambda_{t,t+1}^P p_{t+1}^h g_{t+1}\right) + \kappa\vartheta_t \frac{(h_t^P)^{\epsilon_h}}{\tilde{\lambda}_t^P} + \chi_t(1-\rho_B)mp_t^h$
21. Housing market clearing	$h_t^B + h_t^S = 1$
22. Equity demand	$v_t = (1-\delta_N)\,\mathbb{E}_t\left(\Lambda_{t,t+1}^B(d_{t+1} + v_{t+1})\right)$
23. Equity supply (free entry)	$\phi_t v_t = 1 + AC_{S,t} + AC'_{S,t}s_t - \mathbb{E}_t\left(\Lambda_{t,t+1}^B AC'_{S,t+1}s_{t+1}\right)$
24. Innovators productivity	$\phi_t = \phi s_t^{\rho-1}$
25. Intermediate firms profit	$d_t = \frac{\nu-1}{A}x_t$
26. Growth rate	$g_{t+1} = (1-\delta_N)(1+\phi s_t^{\rho})$
27. Markup	$\mu_t = \frac{\eta}{(\eta-1)+\psi_p\frac{\Pi_t}{\Pi}\left(\frac{\Pi_t}{\Pi}-1\right)-\psi_p\,\mathbb{E}_t\,\Lambda_{t,t+1}^B\left(\frac{\Pi_{t+1}}{\Pi}-1\right)\frac{\Pi_{t+1}}{\Pi}\frac{y_{t+1}}{y_t}g_{t+1}}$
28. Taylor rule	$1 + r_t = \max\left[0; (1+r_{t-1})^{\rho_r}\left((1+r)\left(\frac{y_t^{GDP}}{y^{GDP}}\right)^{\phi_Y}\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi}\right)^{1-\rho_r} u_t\right]$
29. Final output	$y_t = \left(\frac{A\xi}{\nu}\right)^{\frac{\xi}{1-\xi}} Z_t^{\frac{1}{1-\xi}} \mu_t^{\frac{\xi}{\xi-1}} \tilde{k}_t^{\alpha} L_t^{1-\alpha}, \quad \tilde{k}_t = u_t k_t$

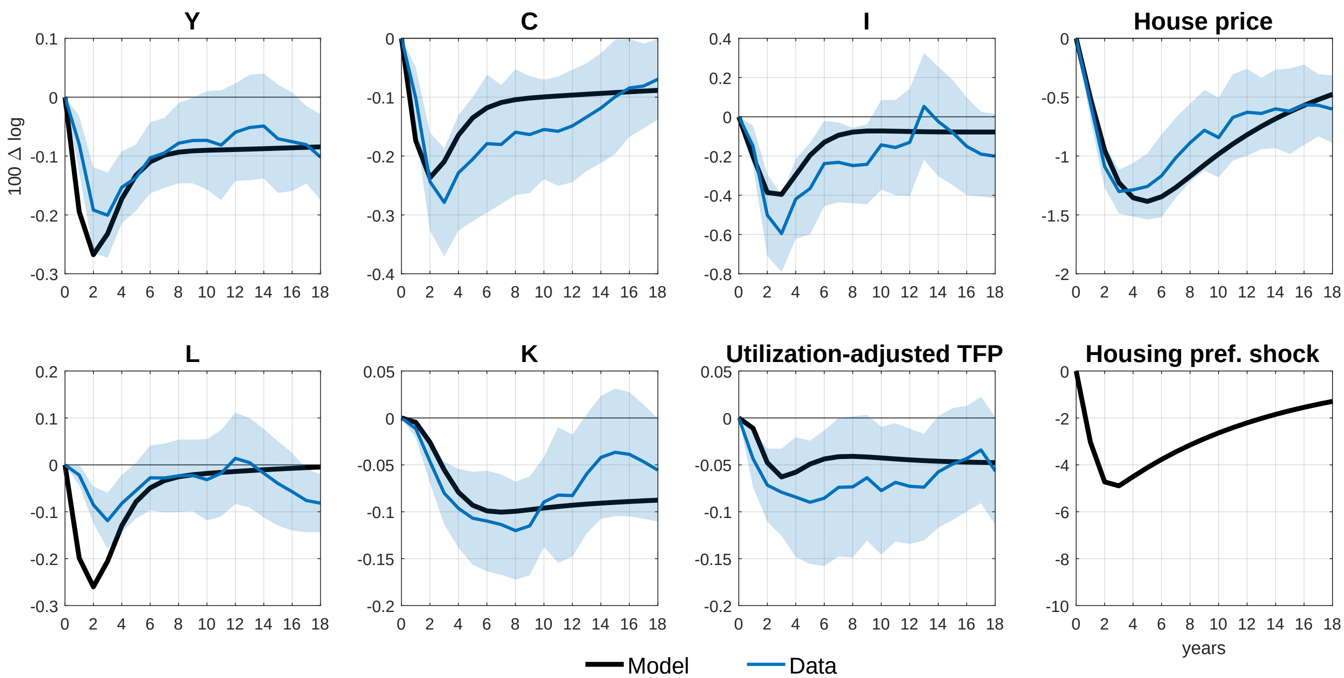
Note: where appropriate, lower-case letters denote stationary counterparts of original variables, i.e. $c_t = \frac{C_t}{N_t}$.

Table 4: Structural parameters [cited on page 25]

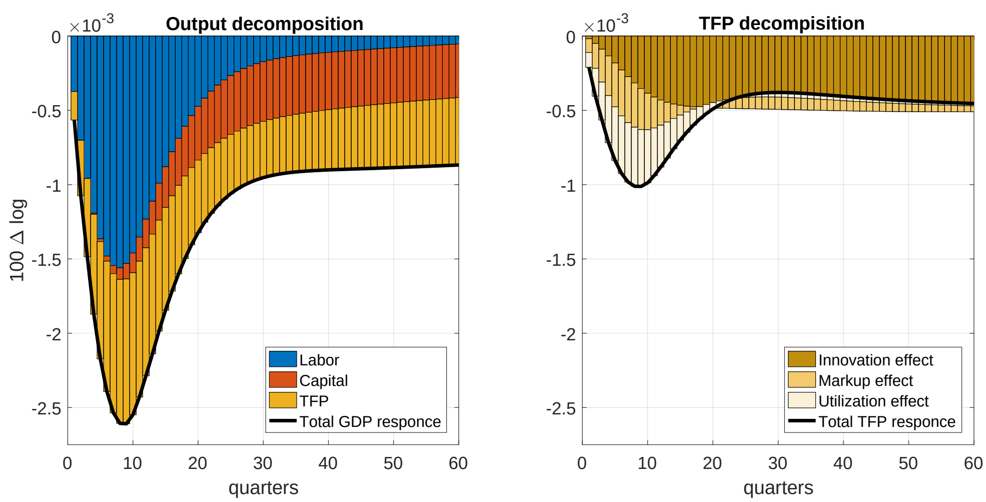
	Calibrated parameters:		Source / target
β_S	Savers discount factor	0.9968	4% annual real interest rate
β_B	Borrowers discount factor	0.9963	$\beta_B = \beta_S - \varepsilon$
σ	Relative risk aversion	2	Conventional
$1/\epsilon_L$	Frisch elasticity of labor supply	1	Conventional
$1/\epsilon_h$	Price elasticity of housing demand	0.2	Hanushek and Quigley (1980)
m	Max leverage	0.75	Warnock and Warnock (2008)
α	Capital share	0.4	Data median, PWT 9.1
$\frac{\nu}{\nu-1}$	Intermediate-good elasticity of subst.	1.6	BGP requirement $\frac{\xi(\nu-1)}{1-\xi} = 1-\alpha$
η	Retail-good elasticity of subst.	11	10% steady-state markup
ξ	Intermediate good share	0.5	Comin and Gertler (2006)
$1/A$	Intermediate sector marginal cost	1	Normalization
ρ	Innovation output elasticity	0.8	Comin and Gertler (2006)
δ_K	Steady state capital depreciation	0.025	Conventional
δ_N	Intermediate sector exit rate	0.025	Bilbiie et al. (2012)
ϕ_y ; ϕ_π; ρ_r	Taylor rule parameters	0.5/4; 1.5; 0.7	Conventional
ϕ	Innovators productivity	0.11	Annual TFP growth = 0.8% (data median, PWT 9.1)
κ	Share of housing in utility	0.03	Mortgage debt to GDP = 0.55, Warnock and Warnock (2008)
$\bar{Z}$	Final sector productivity	1.74	Normalization, $Y^{GDP} = 1$
ψ_p	Price adjustment cost	120	4-quarter average Calvo price ridigity equivalent
	Estimated parameters:		IRF matching
ρ_b	Borrowing limit inertia	0.76	
ρ_Υ	Disutility of labor inetria	0.925	
ψ_K	Investment adjustment cost	1	
ψ_N	Innovation adjustment cost cost	0.5	
c_2	Capital utilization responsiveness	0.08	

FIGURE 7: BASELINE SIMULATION: MODEL VS EVIDENCE [cited on page 31]

(a) IRF matching

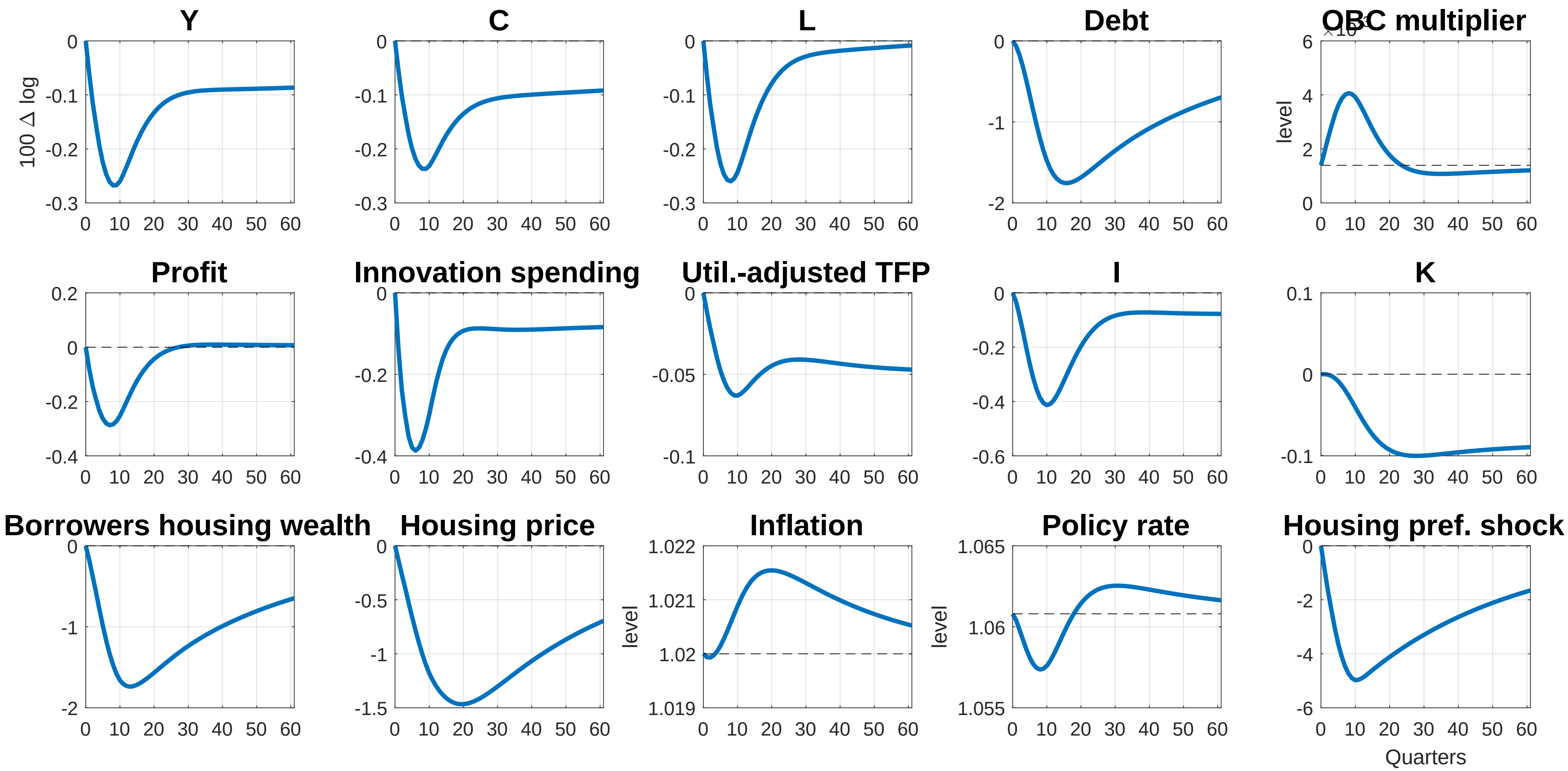


(b) Model-based decompositions



Note: Output decomposition, $\Delta Y_t = \Delta TFP_t + \alpha \Delta K_t + (1-\alpha)\Delta L_t$
TFP residual: $\Delta TPF_t = \underbrace{\Delta\Omega_t}_{\text{Markup}} + \underbrace{\alpha\Delta u_t}_{\text{Utilization}} + \underbrace{(1-\alpha)\Delta N_t}_{\text{Innovation}}$. See details in section 3.4

Figure 8: Baseline simulation, extended set of impulse responses [cited on page 28]

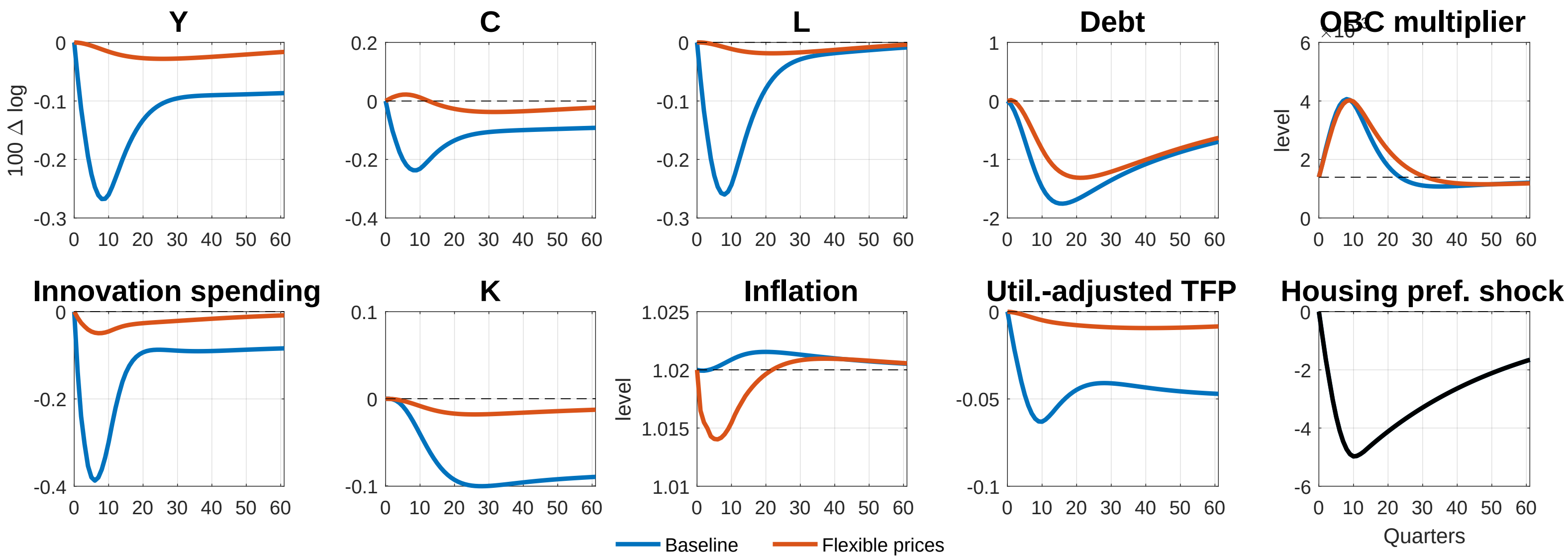


Note: impulse responses to a series of negative housing preference shocks calibrated to match the empirical real house price decline, as in figure 8. Inflation rate and the policy rate are annualized.

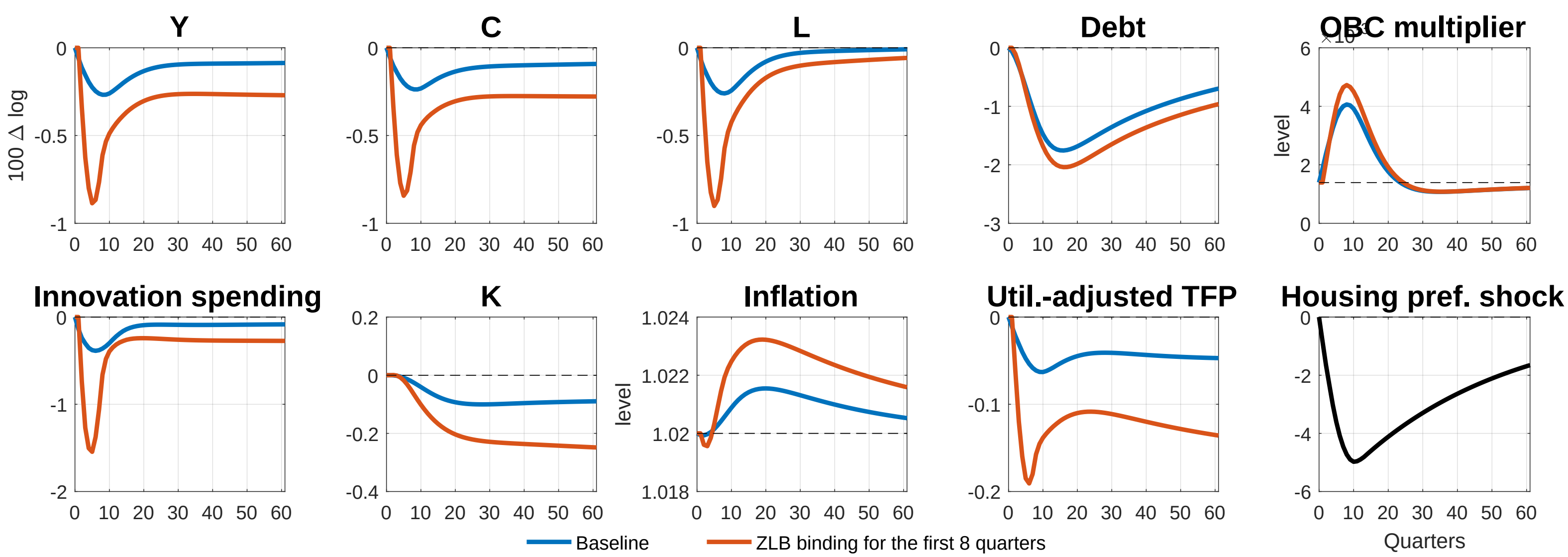
See details in section 4.2.

Figure 9: Baseline simulation, aggregate demand channel [cited on page 30]

(a) The effect of nominal rigidity



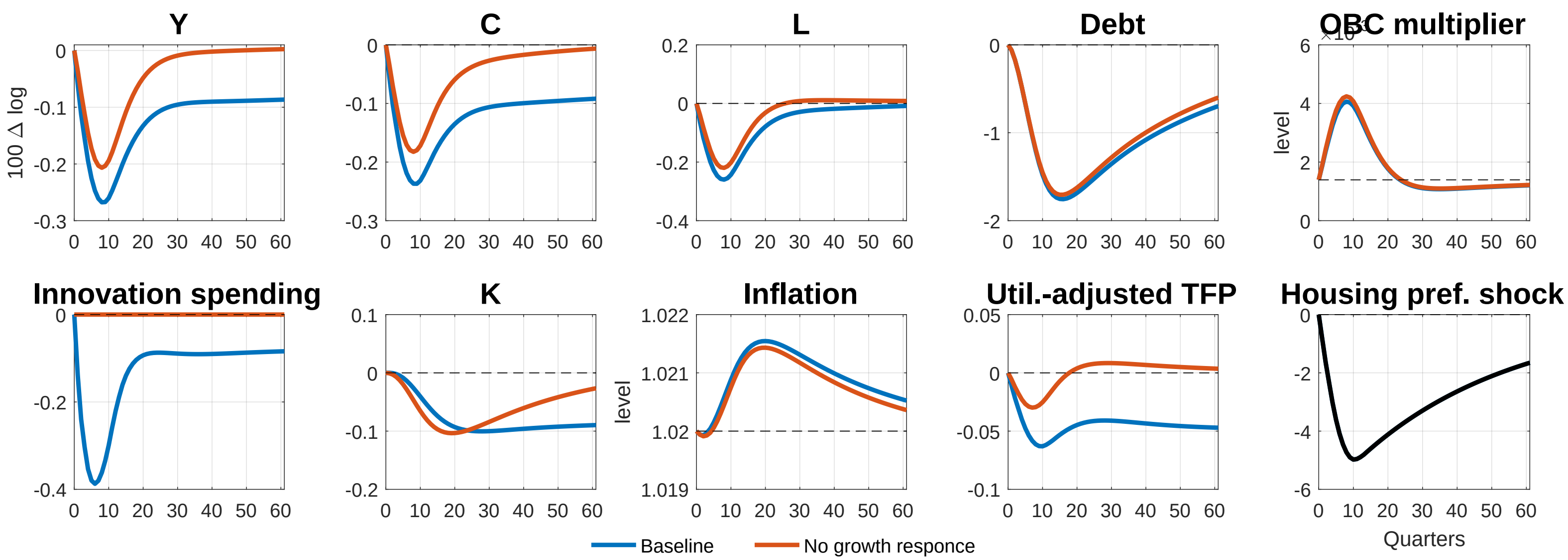
(b) The effect of a binding zero lower bound



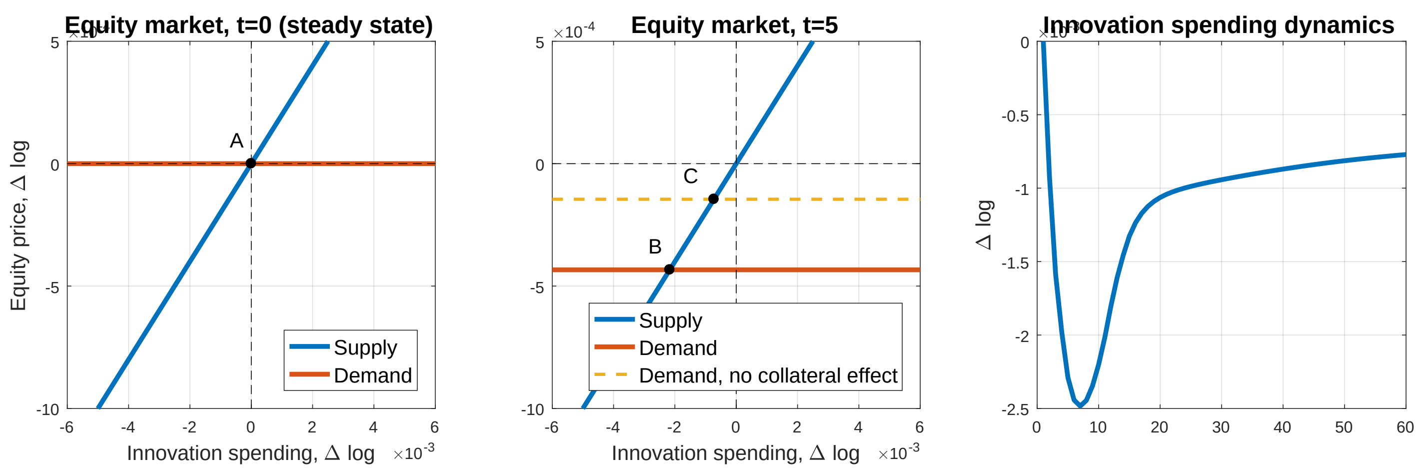
Note: counterfactual responses to the baseline in figure 9. Panel (a): flexible price counterfactual by setting $\psi_p = 0$. Panel (b): net effect of the housing preference shock contingent on a savers discount rate shock that makes the zero lower bound bind for the first 8 quarters. See details in section 5.1.

Figure 10: Baseline simulation, endogenous growth channel [cited on page 31]

(a) No endogenous response of productivity growth



(b) Model-consistent equity market equilibrium

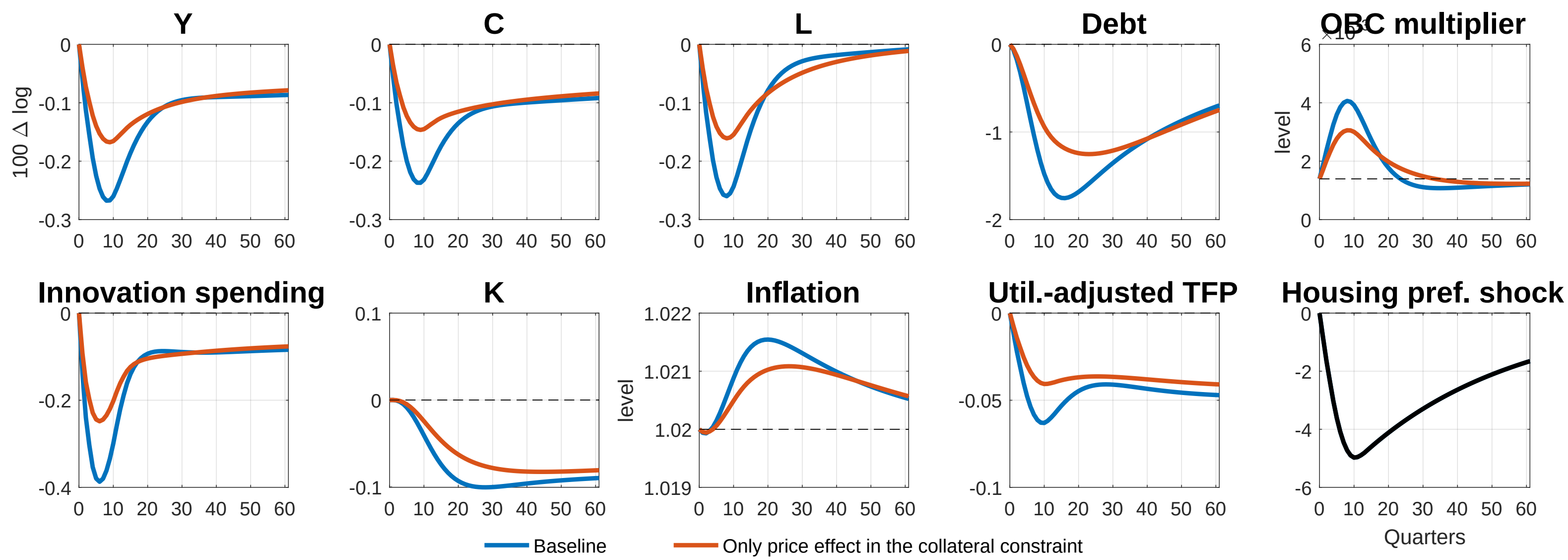


Note: counterfactual responses to the baseline in figure 9. Panel (a): counterfactual without growth responce by setting $\psi_N = 10^5$. Panel (b): intermediate-firm equity market dynamics consistent with the baseline simulation.

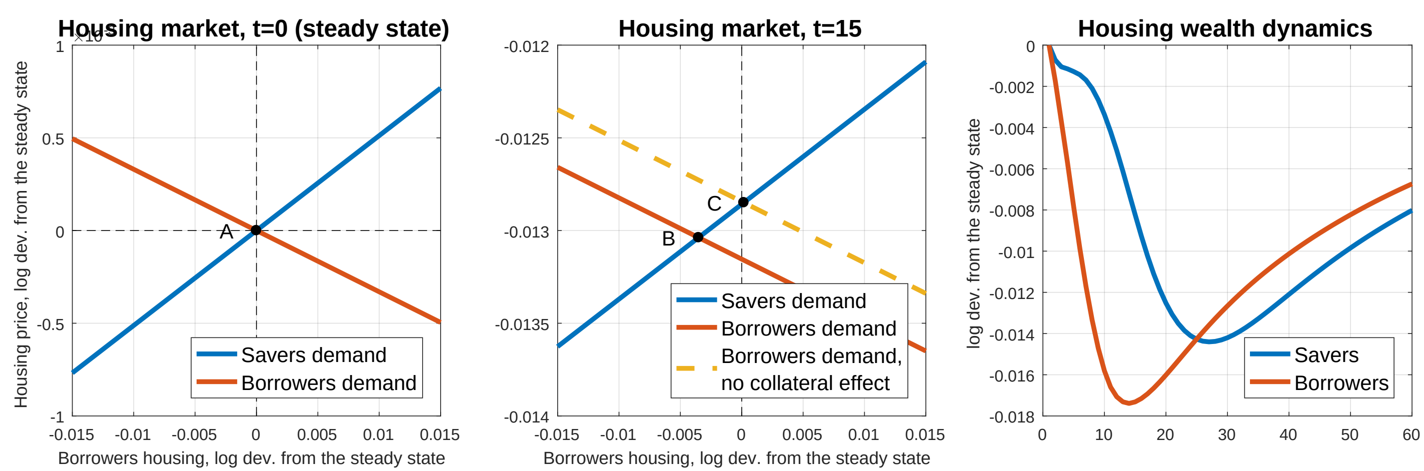
See details in appendix D.3 and section 5.2.

FIGURE 11: BASELINE SIMULATION, FISHERIAN DEBT DEFLATION CHANNEL [cited on page 33]

(a) No housing reallocation effect in the borrowing constraint



(b) Model-consistent housing market equilibrium

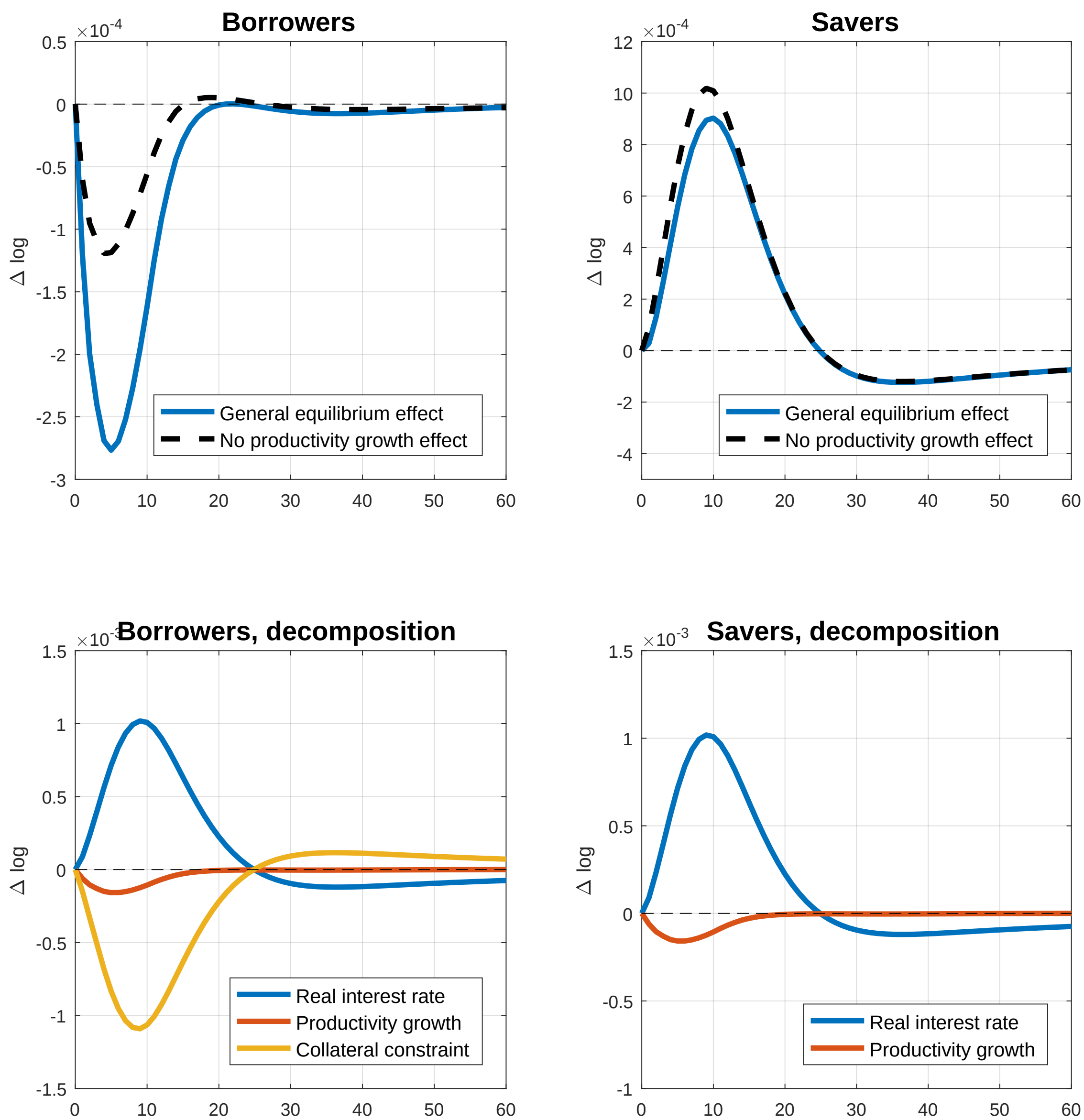


Note: counterfactual responses to the baseline in figure 9. Panel (a): counterfactual by fixing the housing quantity in the borrowing limit $B^B_{t+1}/P_t \leq \rho_B m P^h_t \mathbf{h^B}$. Panel (b): housing market dynamics consistent with the baseline simulation.

See details in appendix D.2 and section 5.3.

Figure 12: Baseline simulation, expected income growth channel [cited on page 33]

Expected growth of marginal utility of consumption:



Note: Decomposition of the marginal utility of consumption growth, baseline simulation in figure 9.

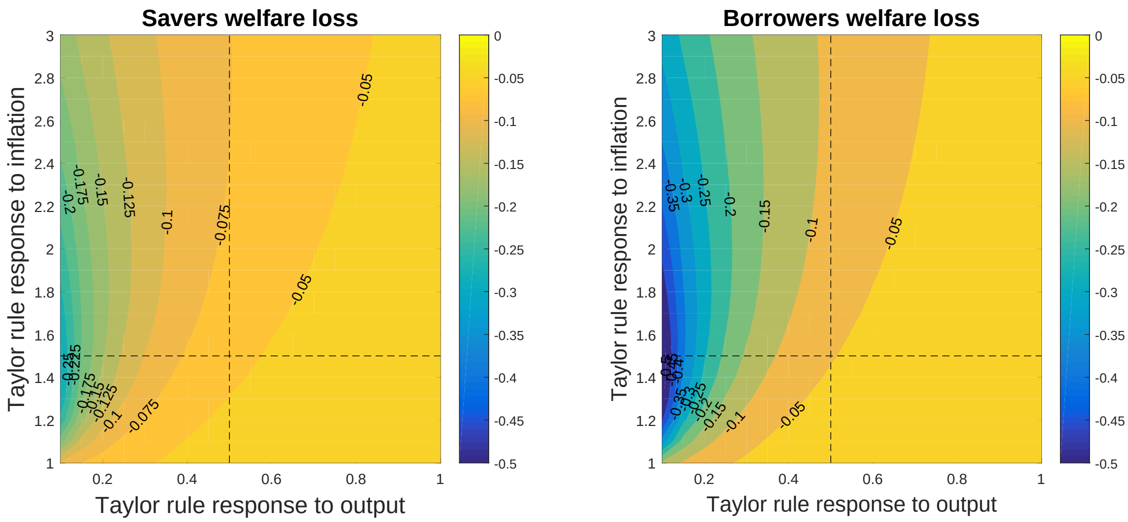
$$\text{Savers:} \quad \mathbb{E}_t\, \mathsf{g}_{\lambda^{\mathsf{S}}_{\mathsf{t+1}}} = \mathbb{E}_t\, \tilde{\lambda}^{\mathsf{S}}_{\mathsf{t+1}} - \tilde{\lambda}^{\mathsf{S}}_{\mathsf{t}} = -\mathbb{E}_t\, \mathsf{R}_{\mathsf{t+1}} + \sigma \mathsf{g}_{\mathsf{t+1}}$$

$$\text{Borrowers:} \quad \mathbb{E}_t\, \mathsf{g}_{\lambda^{\mathsf{B}}_{\mathsf{t+1}}} = \mathbb{E}_t\, \tilde{\lambda}^{\mathsf{B}}_{\mathsf{t+1}} - \tilde{\lambda}^{\mathsf{B}}_{\mathsf{t}} = \underbrace{-\mathbb{E}_t\, \mathsf{R}_{\mathsf{t+1}}}_{\text{Real interest rate}} + \underbrace{\sigma \mathsf{g}_{\mathsf{t+1}}}_{\text{Productivity growth}} \underbrace{-A^B_{\Lambda 1}\chi_{\mathsf{t}} + A^B_{\Lambda 2}\, \mathbb{E}_t(\chi_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \Pi_{\mathsf{t+1}})}_{\text{Collateral constraint wedge}}$$

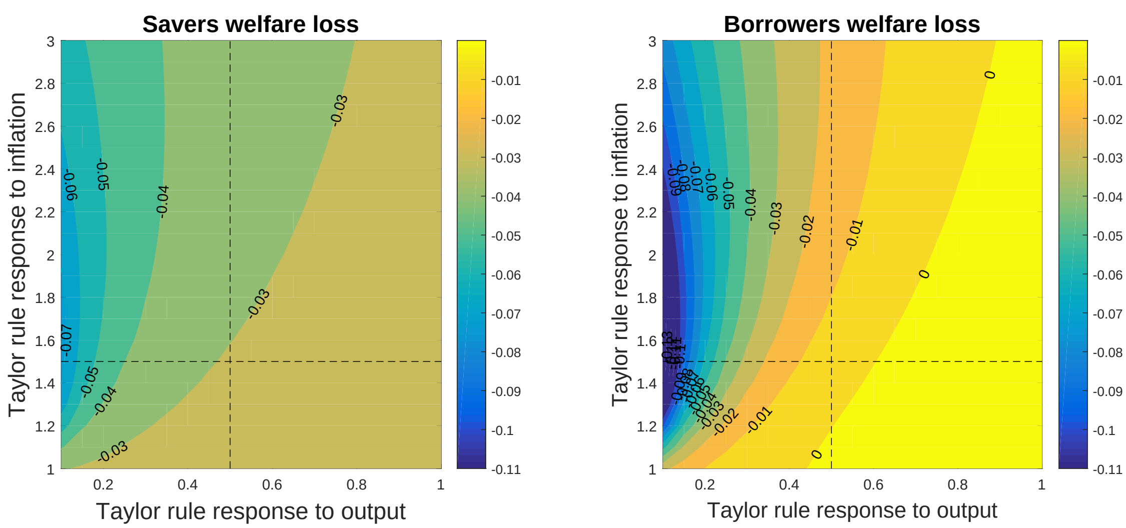
See details in appendix D.4 and section 5.4.

Figure 13: Baseline simulation, welfare cost and monetary policy [cited on page 34]

(a) Model with endogenous growth response (% of steady-state consumption)



(b) Model without endogenous growth response (% of steady-state consumption)



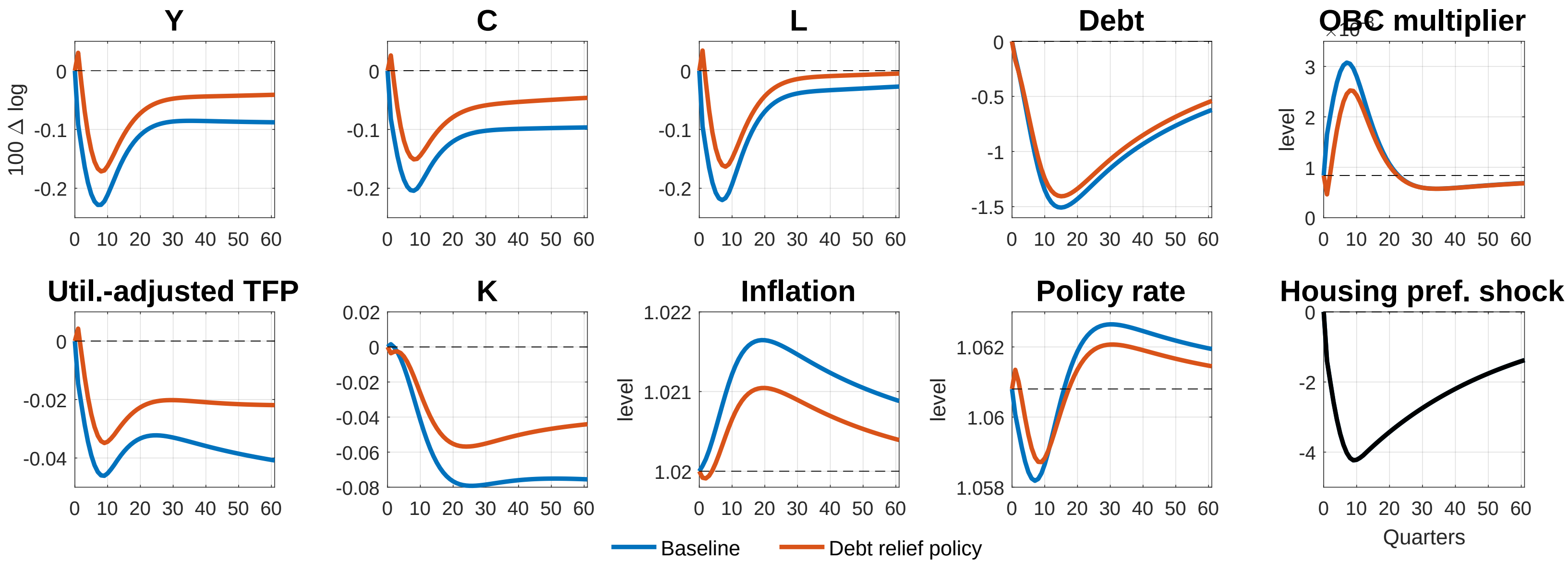
Note: counterfactual scenarios to the baseline in figure 9 under different parameters of the Taylor rule: $1 + r_t = (1 + r_{t-1})^{\rho_r} \left((1 + r) \left(y_t^{GDP} / y^{GDP} \right)^{\phi_Y} (\Pi_t / \Pi)^{\phi_\Pi} \right)^{1-\rho_r}$.

The welfare cost is expressed in steady-state consumption equivalent under different values of parameters that govern the policy rate reaction to output (ϕ_Y) and inflation (ϕ_Π). In all cases the interes rate inertia is set to the baseline value of $\rho_r = 0.7$. Dashed lines mark baseline values of parameters.

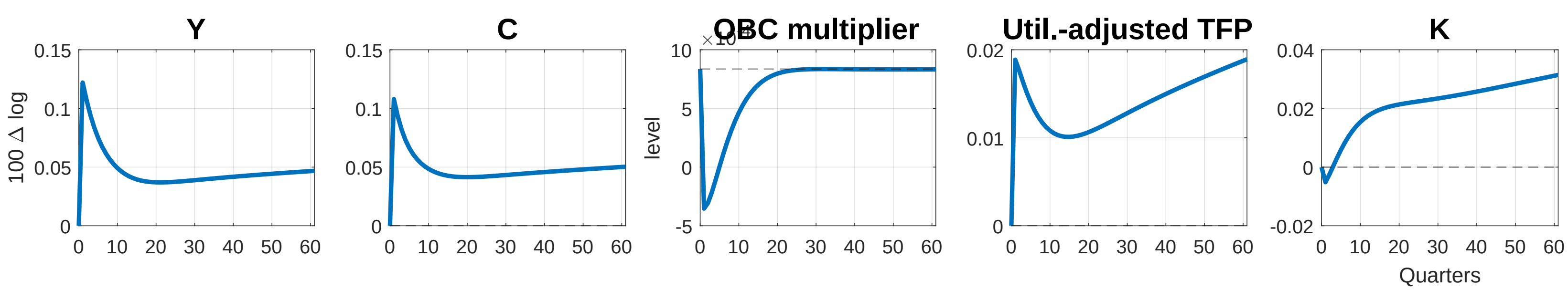
See details in section 6.

Figure 14: Baseline simulation, debt relief policy [cited on page 35]

(a) Baseline simulation vs policy



(b) Net effect of the policy



Note: counterfactual scenario to the baseline in figure 9. Inflation rate and the policy rate are annualized.

Debt relief policy consists of a temporary transfer from savers to borrowers equivalent to a 0.25% of borrowers steady-state debt burden implemented at the time of the shock. See details in section 6.

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Housing market cycles, productivity growth, and household debt

Online appendix

Dmitry Brizhatyuk*

Abstract

The appendix gathers supplementary materials to Brizhatyuk (2020)

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A Data appendix

World Bank, 1960-2018 data.worldbank.org/indicator

GDP per capita, constant LCU *NY.GDP.PCAP.KN*
Households and NPISHs final consumption expenditure, constant LCU, *NE.CON.PRVT.KN*
Gross fixed capital formation, constant LCU *NE.GDI.FTOT.KN*
GDP deflator *NY.GDP.DEFL.ZS*

Penn World Table version 9.1, 1950-2017 rug.nl/ggdc/productivity/pwt

Output-side real GDP at chained PPPs (in mil. 2011 USD) *rgdpo*
Population (in millions) *pop*
Number of persons engaged (in millions) *emp*
TFP at constant national prices (2011=1) *rtfpna*
Capital stock at constant 2011 national prices (in mil. 2011 USD) *rnna*
Share of merchandise exports at current PPPs *csh_x*
Share of merchandise imports at current PPPs *csh_m*
Share of labour compensation in GDP at current national prices *labsh*

IMF Global Debt Database, 1950-2017 imf.org/external/datamapper/datasets/GDD

Household debt, loans and debt securities, percent of GDP
Nonfinancial corporate debt, loans and debt securities, percent of GDP

Jordà-Schularick-Taylor Macrohistory Database http://www.macrohistory.net/data

House prices (nominal index, 1990=100) *hpnom*
Total loans to households (nominal, local currency) *thh*
Total loans to business (nominal, local currency) *tbus*
Consumer prices (index, 1990=100) *cpi*

Aggregate real house price indexes, other sources

BIS real residential property indices bis.org/statistics/pp_selected.htm
Dallas FED International House Price Database dallasfed.org/institute/houseprice
OECD real house price indices stats.oecd.org/Index.aspx?DataSetCode=HOUSE_PRICES

Laeven and Valencia (2013) sites.google.com/site/laevenl/codes

Systemic Banking Crises Database

Ilzetzki et. al. (2019) carmenreinhart.com/data/browse-by-topic/topics/11

Exchange rate regime classification

Bruegel bruegel.org/publications/datasets

Real effective exchange rates

Table 5: Country sample

ARG	BRA	CZE	FIN	HRV	ISR	LUX	NOR	PRT	SVN
AUS	CAN	DEU	FRA	HUN	ITA	LVA	NZL	RUS	SWE
AUT	CHE	DNK	GBR	IDN	JPN	MEX	PER	SGP	THA
BEL	CHL	ESP	GRC	IRL	KOR	MYS	PHL	SRB	USA
BGR	COL	EST	HKG	ISL	LTU	NLD	POL	SVK	ZAF

Note: List of 50 countries with available aggregate housing price indices, ISO 3166-1 alpha-3 codes. Countries for which no housing bubbles have been identified are highlighted.

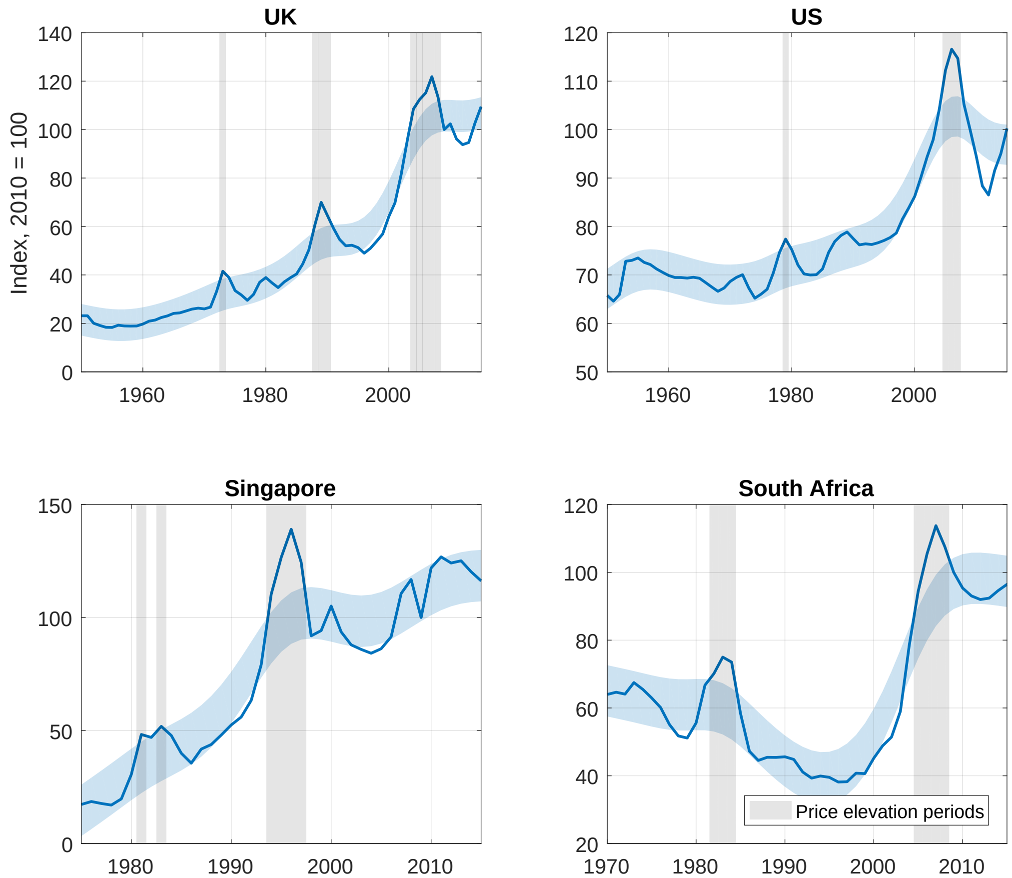
Table 6: Summary statistics [cited on page and 9]

		Obs	Mean	Median	Std. dev.
1.	ΔY	2,485	0.025	0.025	0.034
2.	ΔC	2,230	0.032	0.031	0.031
3.	ΔI	2,370	0.037	0.041	0.102
4.	ΔK	2,890	0.027	0.022	0.022
5.	ΔL	2,890	0.002	0.001	0.019
6.	ΔTFP	2,690	0.007	0.008	0.028
7.	$\Delta TFP_{adjusted}$	2,690	0.007	0.007	0.023
8.	$\Delta B_{household}$	1,655	1.063	0.888	2.539
9.	ΔB_{firm}	1,637	1.268	0.951	8.947
10.	ΔP_{house}	1,822	0.022	0.019	0.092
11.	ΔP	2,485	0.106	0.044	0.290
12.	$\Delta Y/L$	2,890	0.022	0.022	0.036
13.	RER	2,637	102.120	96.411	42.165
14.	Nx/Y	2,940	-0.033	-0.021	0.108
15.	Ex/Y	2,940	0.306	0.206	0.319
16.	Im/Y	2,940	-0.339	-0.246	0.349
17.	L share	3,120	0.565	0.584	0.099
18.	I share	2,940	0.253	0.249	0.083
Conditional on a peak of a housing market cycle at t:					
19.	$\Delta_3 P_{house,t+3}$	63	-0.242	-0.216	0.106
20.	$\hat{B}_{household,t}$	48	3.600	3.955	4.381
21.	$\hat{B}_{firm,t}$	47	5.821	5.472	8.506

Note: unbalanced panel of 50 countries, 1950-2018, Δ denotes log deviation. (1) Real GDP per capita; (2) Real consumption per capita; (3) Real investment per capita; (4) Real capital stock per-capita; (5) Employment-to-population ratio; (6) TFP index; (7) Utilization-adjusted TFP index; (8) Household debt, loans and debt securities, % of GDP; (9) Nonfinancial corporate debt, loans and debt securities, % of GDP. Where applicable, the IMF Global Debt Database data is extended backwards using banking lending data from the Jordà-Schularick-Taylor Macrohistory Database; (10) National real housing price index; (11) GDP-deflator; (12) Real output per worker; (13) Real exchange rate index; (14) Net exports to GDP; (15) Exports to GDP; (16) Imports to GDP; (17) Labor share of GDP; (18) Investment share og GDP

Conditional on a peak of a housing market cycle att t: (19) Real housing price index decline in the first 3 years from the peak; (20) Household debt-to-GDP gap at the peak of the housing market cycle; (21) Firm debt-to-GDP gap at the peak of the housing market cycle.

Figure 15: Housing market boom-and-bust cycles definition [cited on page 10]



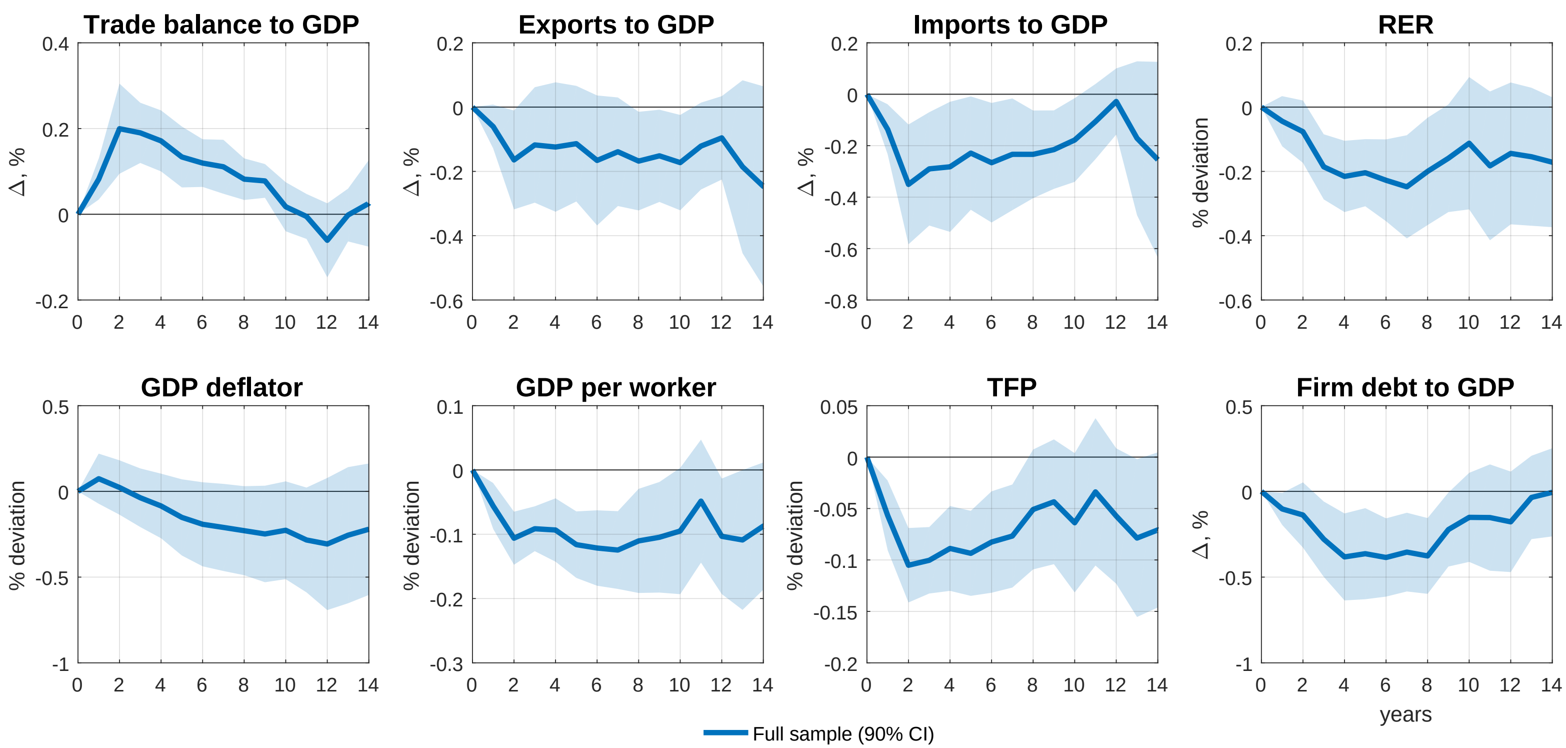
Note: definition similar to Jordà et al. (2015). Blue shaded areas correspond to a 1 st. dev. bound aroung the one-cided HP trend (smoothing parameter $= 400000/4^4$).

Housing market crashes are defined as periods when (1) the aggregate housing price index deviates from the long-run trend by more than one standard deviation (marked by gray shaded areas) and (2) exhibit the price decline of at least 10% within the first three years from the peak.

B Additional empirical results

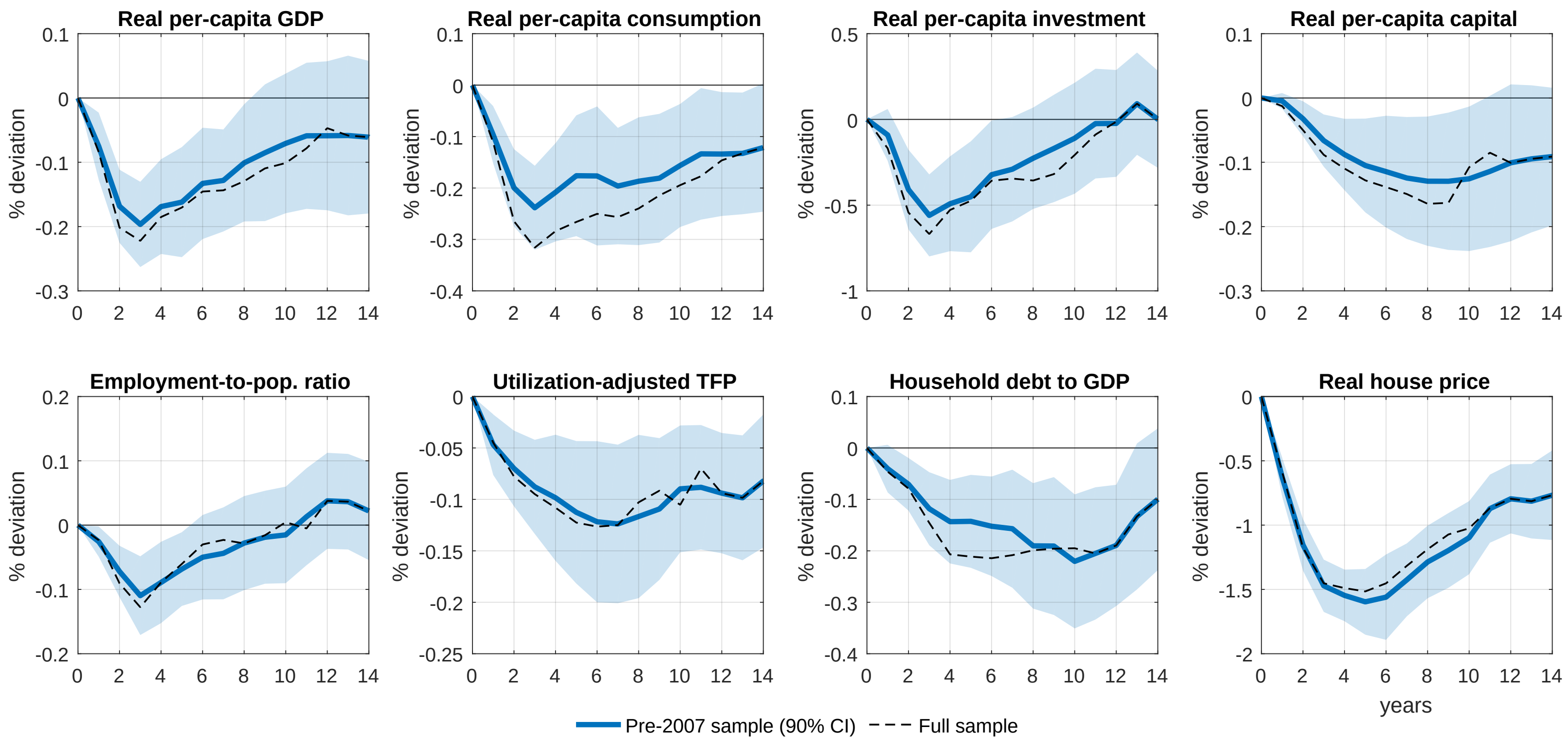
B.1 Cross-country panel

FIGURE 16: AN AVERAGE HOUSING MARKET CRASH, ADDITIONAL RESULTS



Note: cross-country panel estimation, controlling for country and year fixed effects, country-specific trends, and preexisting macroecnomic conditions. Responses are estimated by local projections and are expressed in log deviations times 100 (see details in the text). Shaded areas correspond to 90% confidence intervals. Standard errors are clustered at the country level.

Figure 17: Impulse responses to a housing market crash, pre-2007 sample



Note: cross-country panel estimation, the baseline specification (1) controlls for country/time fixed effects, country-level trends, and macroecnomic conditions. Alternatives: (2) Baseline, excluding observations from 2007; (3) 4 lags of macro controls instead of 2; (4) No macro controls; (5) No macro controls and year fixed effects.

Responses are estimated by local projections and are expressed in log deviations times 100 (see details in the text). Shaded areas correspond to 95% confidence intervals of the baseline IRFs. Standard errors are clustered at the country level.

B.2 Cross-country panel: the role of credit imbalances

Figure 18: US credit and housing cycles

Note: a debt-to-GDP gap is defined as a deviation of the debt-to-GDP ratio from the the long-run HP trend (smoothing parameter of $10^5/4^3$ for annual observations). The data on household and non-financial corporate debt comes from the IMF Global Debt Database and includes both loans and debt securities.

Does the credit intensity of the housing market boom exacerbate the macroeconomic effects of the subsequent bust? Jordà et al. (2015) show that recession associated with housing market crashes tend to be deeper when preceded by higher than average bank lending growth. I revisit this result using the novel IMF's Global Debt Database that contains separate data on household and non-financial corporate debt harmonized across counties.

I first calculate household and non-financial corporate debt-to-GDP gaps, which I denote as $\hat{B}_{HH}$ and $\hat{B}_F$ respectively. Similarly to output gaps, these variables are defined as deviations of the debt-to-GDP ratio from its long-run trend, defined using the one-sided HP filter.[1] I use debt-to-GDP gaps as a measure of credit intensity of housing market booms relative to the secular trend of financialization. The above figure plots US debt-to-GDP gaps along with the house price dynamics. The figure illustrates that the cyclical dynamics of the US housing market

[1] Following the BIS definition the smoothing parameter is set to $4 \cdot 10^5/4^4$. This variable has recently became popular among policymakers as a reduced-form way to capture credit imbalances. For instance, it is used in the Basel III regulatory framework as a guide for setting countercyclical capital buffers.

correlates more closely with the dynamics of household, rather than corporate, indebtedness. This pattern holds across most industrialized countries. A such, [XXX].

I extend the baseline empirical specification, equation (1), by adding interactions between the price decline and the peak debt-to-GDP gaps to test whether preexisting credit imbalances affect the transmission of house price declines:[2]

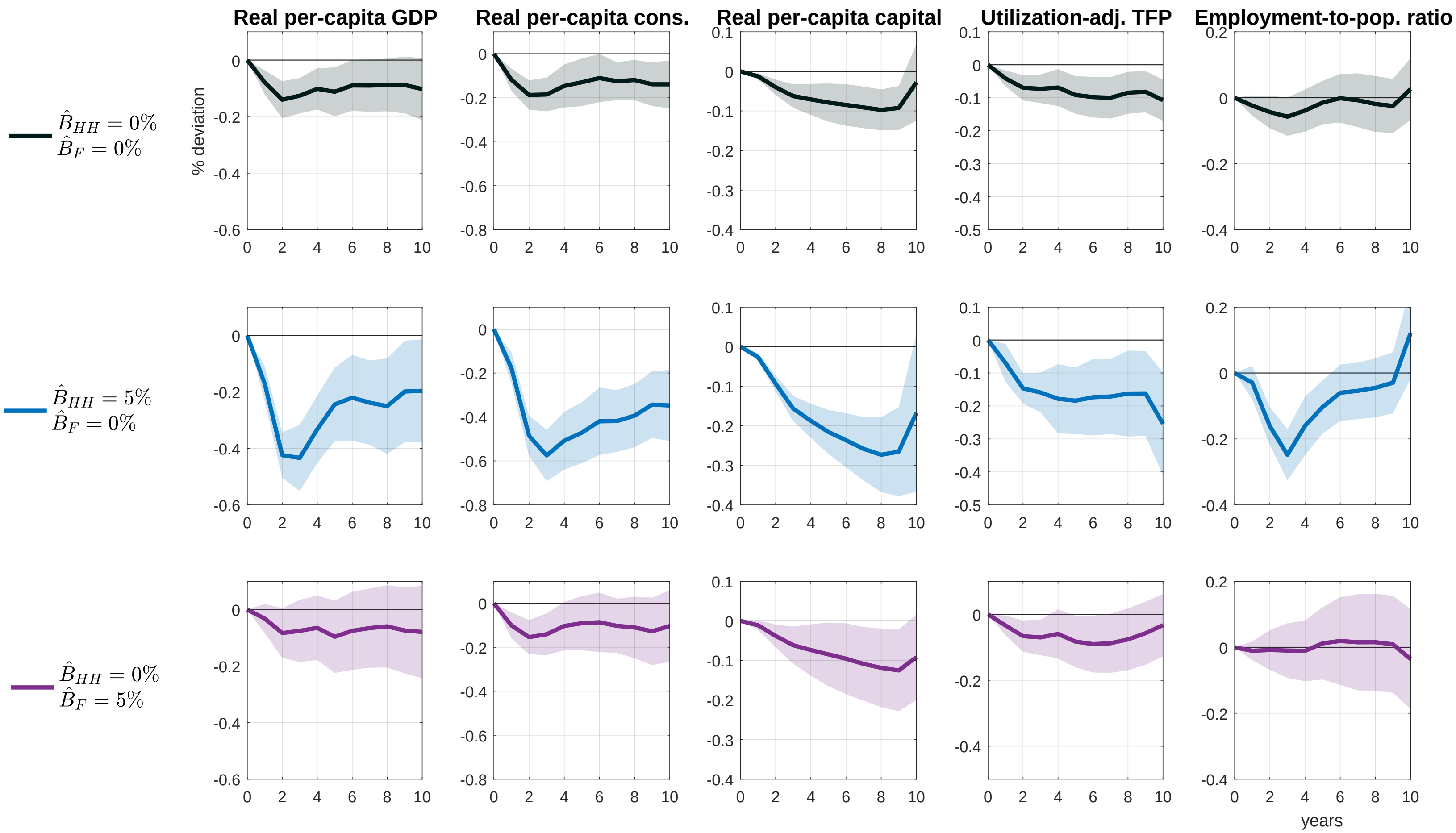
$$\Delta_h y_{i,t+h} = \alpha_i^h + \alpha_t^h + (\beta^h + \beta_{HH}^h \hat{B}_{i,t}^{HH} + \beta_F^h \hat{B}_{i,t}^F)\Delta p_{i,t}^{\text{crash}} + \hat{B}_{i,t}^{HH} + \hat{B}_{i,t}^F + X_{i,t}\Gamma + \varepsilon_{it}^h \tag{B.1}$$

To assess the relative role of household and corporate debt, I then calculate marginal effects of the house price decline at different values of household and corporate debt-to-GDP gaps. For illustrative purposes I consider the two scenarios when household credit gap is 5% and corporate credit gap is 0% and the other way around. Figure 20 shows the corresponding conditional impulse responses for output, consumption, and employment. The main message from this result is the following. The same house price decline is associated with a deeper recession and a slower recovery when household — but not corporate — debt-to-GDP gap is high. In other words, a rapid preceding expansion of household debt tends to exacerbate the effect of housing market crashes.

This evidence is consistent with the results of Mian et al. (2017) who uncover the (unconditional) detrimental effect of increases in the household debt on growth and employment in the medium run.

[2] The sample reduces as the debt data is available for only 50 events.

Figure 19: An average housing market crash, the role private debt [cited on page 9]



Note: cross-country panel estimation, controlling for country and year fixed effects, country-specific trends, and preexisting macroeconomic conditions, as well as corporate and household credit-to-GDP gaps at the onset of the crash. Responses of variables per 1% on-impact decrease in the aggregate house price conditional on credit-to-GDP gaps.

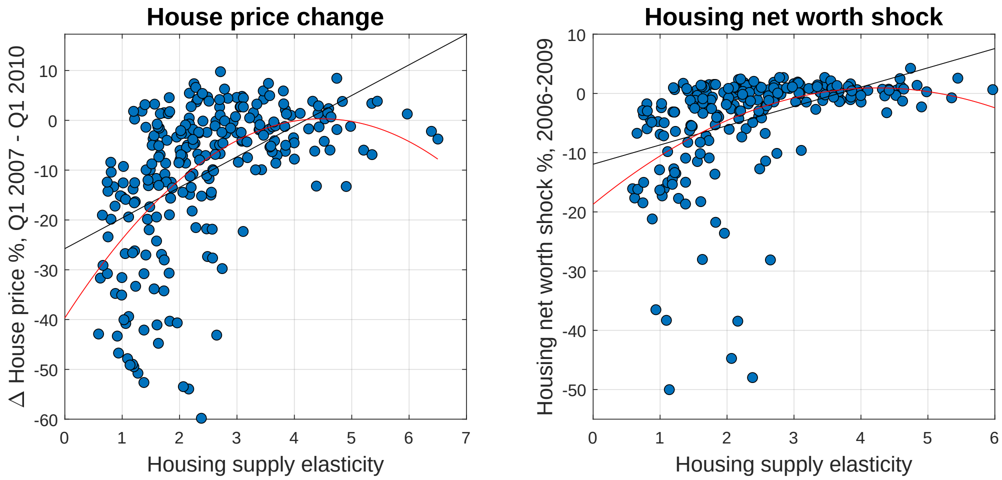
Variables: (1) Real per-capita GDP; (2) Real per-capita consumption; (3) Real per-capita capital stock; (4) Total factor productivity, utilization-adjusted; (5) Employment-to-population ratio.

Responses are estimated by local projections and are expressed in log deviations times 100. Shaded areas correspond to 90% confidence intervals. Standard errors are clustered at the country level.

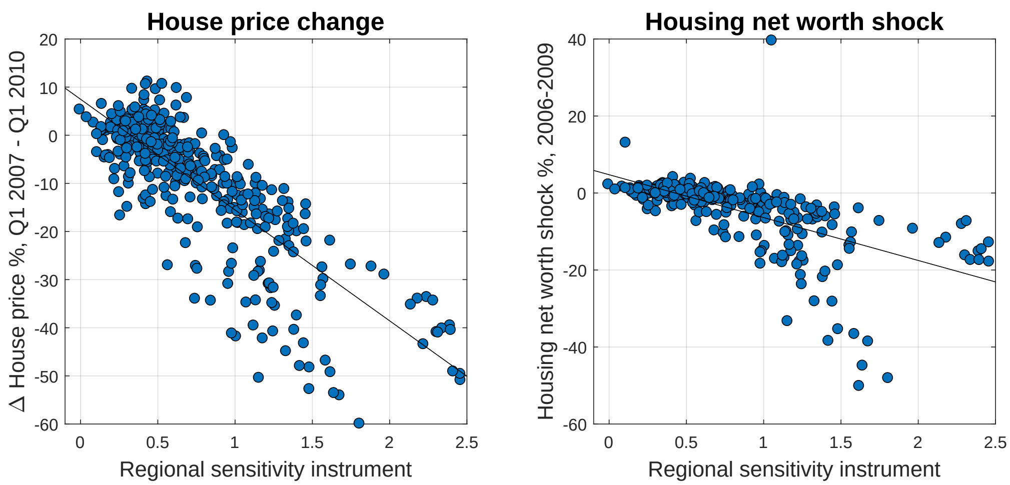
B.3 US MSA-level evidence

Figure 20: US MSA-level evidence, first stage regressions [cited on page ??]

(a) Saiz (2010) housing supply elasticity instrument
(linear and quadratic first-stage regressions)



(b) Guren et al. (2018) regional sensitivity instrument



Note: labor productivity is defined as real GDP per worker. State and MSA output and employment data is from BEA. Housing price growth is based on the Federal Housing Finance Agency all-transactions house price indexes. Housing net worth shock is from Mian and Sufi (2014).

Similarly to Kaplan et al. (2016), given the non-linear relationship between the house price decline and the Saiz (2010) housing supply elasticity I consider a quadratic polynomial in the housing supply elasticity index as an instrument in addition to the standard linear first-stage specification.

Figure 21: Housing net worth shock and labor productivity growth

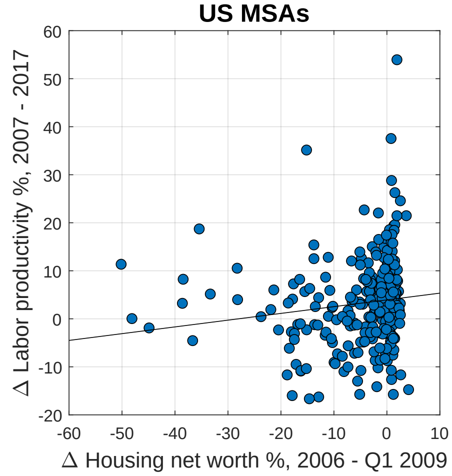
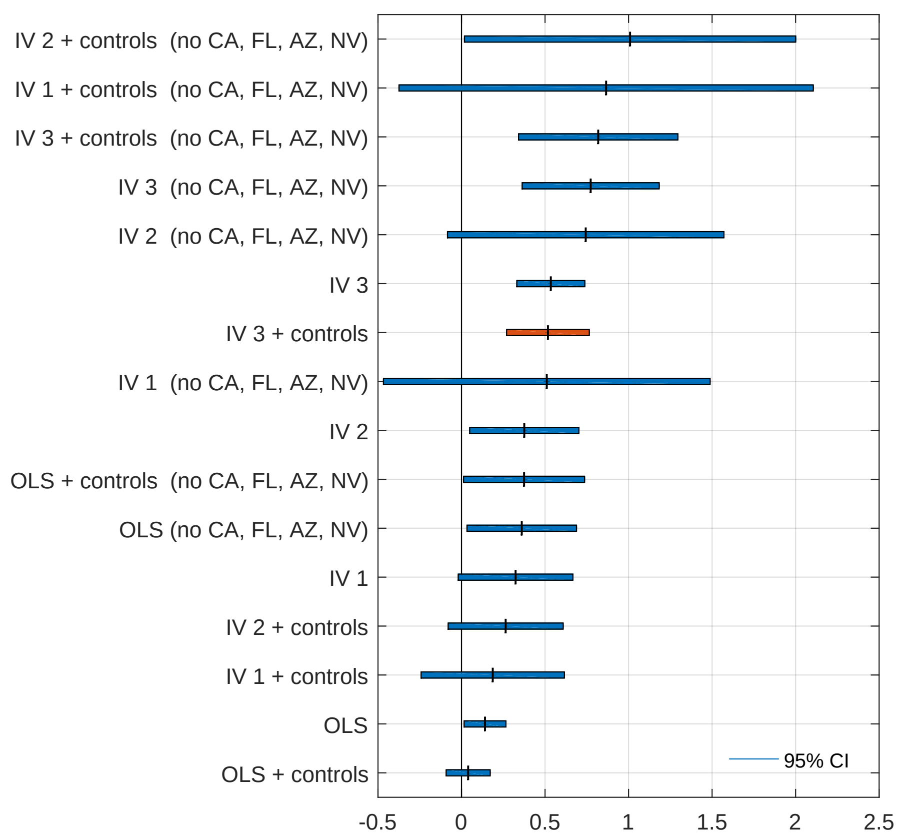


Figure 22: Elasticity of labor productivity growth to housing net worth shock



Note: Baseline specification is in red, see details in table 8.

Table 7: Elasticity of labor productivity growth to housing net worth shock

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ housing net worth 2006-2010	0.14**	0.32*	0.38**	0.53***	0.36**	0.51	0.74*	0.77***
	(0.06)	(0.18)	(0.17)	(0.10)	(0.17)	(0.50)	(0.42)	(0.21)
Constant	0.04***	0.04***	0.05***	0.06***	0.05***	0.04***	0.05***	0.05***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Observations	309	223	223	308	257	183	183	256
Specification	OLS	IV1	IV2	IV3	OLS	IV1	IV2	IV3
Controls								
Excluding CA, FL, NV, AZ					+	+	+	+

	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Δ housing net worth 2006-2010	0.04	0.19	0.26	0.52***	0.37**	0.87	1.01**	0.82***
	(0.07)	(0.22)	(0.18)	(0.13)	(0.18)	(0.63)	(0.51)	(0.24)
GDP construction share, 2006	-0.91**	-1.03*	-0.95*	-0.46	0.30	0.68	0.72	0.53
	(0.40)	(0.53)	(0.51)	(0.44)	(0.50)	(0.73)	(0.71)	(0.52)
Constant	0.05	-0.01	-0.02	0.04	0.01	-0.11	-0.12	-0.03
	(0.07)	(0.11)	(0.11)	(0.08)	(0.10)	(0.14)	(0.15)	(0.09)
Observations	255	184	184	255	206	145	145	206
Specification	OLS	IV1	IV2	IV3	OLS	IV1	IV2	IV3
Controls	+	+	+	+	+	+	+	+
Excluding CA, FL, NV, AZ					+	+	+	+

Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: labor productivity is defined as real GDP per worker. State and MSA output and employment data is from BEA. Housing net worth shock is defined as a percent change in household net worth between 2006 and 2009 that comes from the collapse in house prices, source: Mian and Sufi (2014). Controls: 2006 shares in GDP of (a) mining, quarrying, and oil and gas extraction; (b) construction; (c) manufacturing; (d) retail trade; as well as (e) 2006 per capital personal income. Reduced sample explides four states that were affected by the housing market crash the most.

IV 1: Saiz (2010) housing supply elasticity instrument, linear first stage; IV 2: Saiz (2010) housing supply elasticity instrument, quadratic first stage; IV 3: Guren et al. (2018) regional sensitivity instrument.

Figure 23: House price boom and labor productivity growth

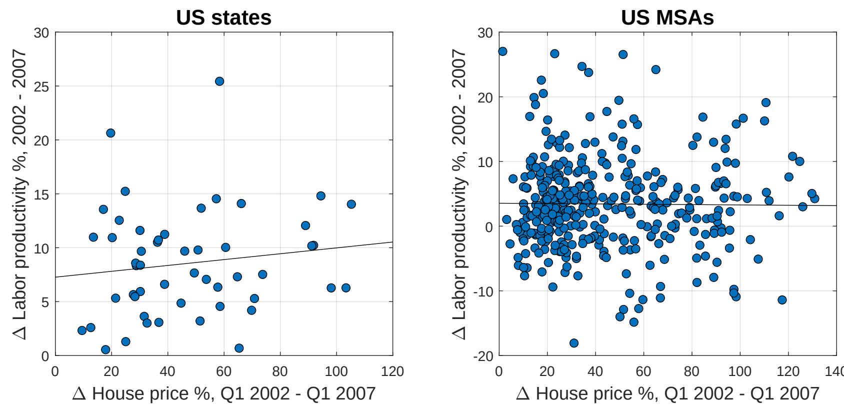


Table 8: Elasticity of labor productivity growth to house price growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ house price 2002-2007	-0.00	-0.06*	-0.03	-0.03	0.05***	-0.04	0.01	-0.01
	(0.01)	(0.03)	(0.03)	(0.02)	(0.02)	(0.05)	(0.05)	(0.03)
Constant	0.04***	0.06***	0.05***	0.05***	-0.00	0.09	0.09	0.02
	(0.01)	(0.02)	(0.01)	(0.01)	(0.06)	(0.09)	(0.09)	(0.06)
Observations	383	250	250	380	312	200	200	310
Specification	OLS	IV1	IV2	IV3	OLS	IV1	IV2	IV3
Controls					+	+	+	+

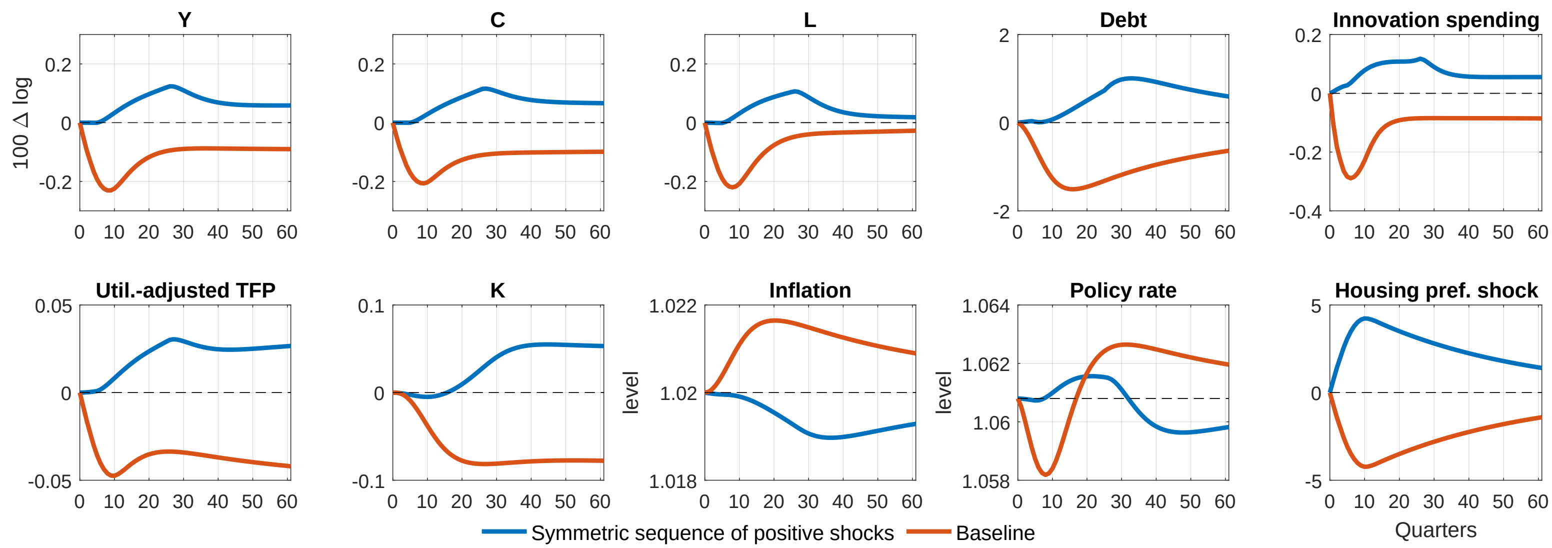
Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: labor productivity is defined as real GDP per worker. State and MSA output and employment data is from BEA. House price growth is based on FHFA all-transactions house price indexes. Controls: 2006 shares in GDP of (a) mining, quarrying, and oil and gas extraction; (b) construction; (c) manufacturing; (d) retail trade; as well as (e) 2006 per capital personal income. Reduced sample explides four states that were affected by the housing market crash the most.

IV 1: Saiz (2010) housing supply elasticity instrument, linear first stage; IV 2: Saiz (2010) housing supply elasticity instrument, quadratic first stage; IV 3: Guren et al. (2018) regional sensitivity instrument.

C Additional simulation results

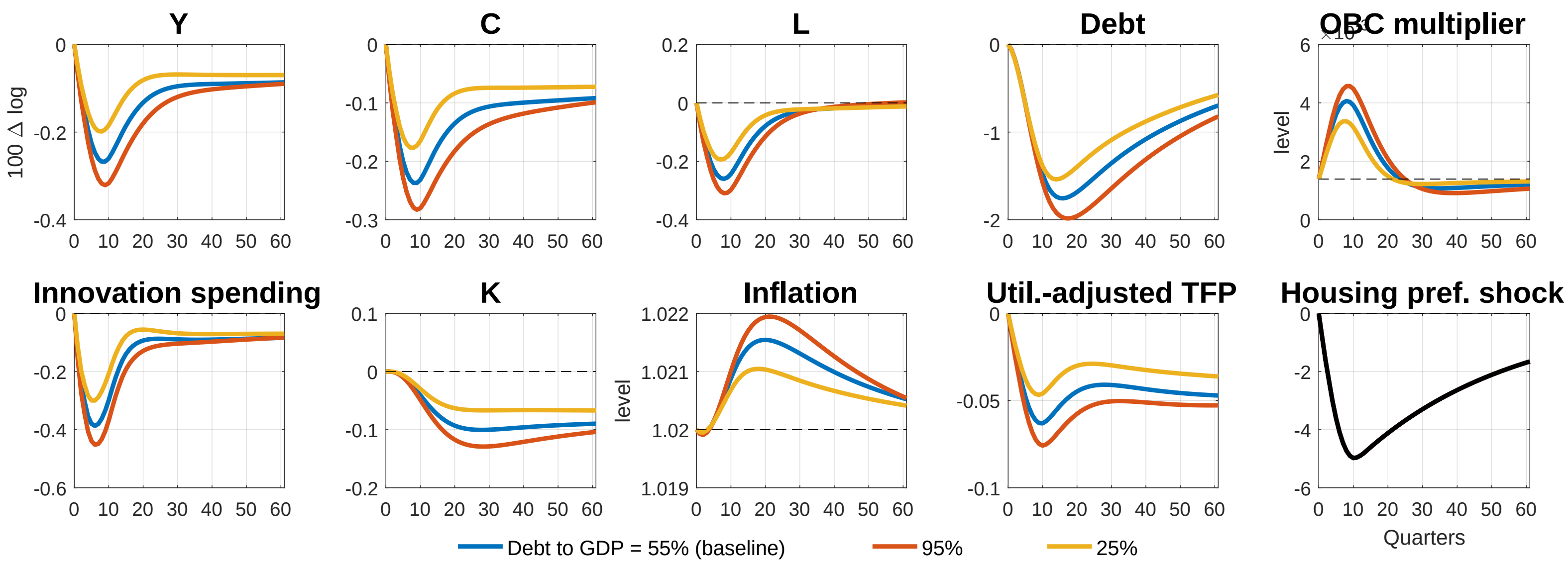
Figure 24: Sign-dependent effects of housing preference shocks [cited on page ??]



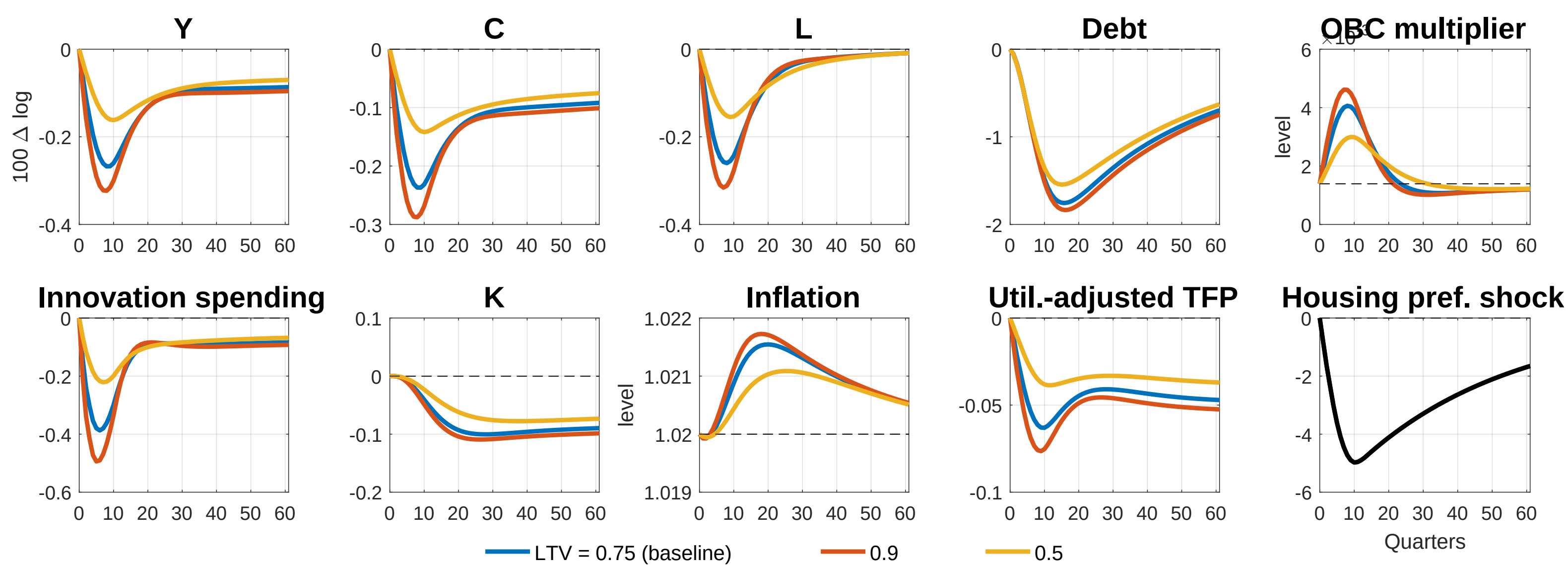
Note: baseline simulation and responses to a symmetric sequence of positive shocks. Inflation rate and the policy rate are annualized.

Figure 25: Baseline simulation, the role household debt [cited on page 29]

(a) Sensitivity to the initial debt to GDP ratio



(b) Sensitivity to the initial loan-to-value ratio



Note: counterfactual responses to the baseline in figure 9. Inflation rate and the policy rate are annualized.

D Derivations

D.1 Utilization-adjusted TFP

I follow the approach of Imbs (1999) who employs a partial-equilibrium version of a model from Burnside and Eichenbaum (1996). The aggregate production function is Cobb-Douglas in effective capital and labor services: $Y_t = Z_t(u_t K_t)^\alpha (e_t L_t)^{1-\alpha}$, where u_t is capital utilization rate and e_t is labor effort, so that the Solow residual equals $Z_t u_t^\alpha e_t^{1-\alpha}$. Capital utilization is endogenized by assuming that it affects capital depreciation: $\delta_t = \delta u_t^\phi$. Firms labor is assumed to be predetermined within one period, while the labor effort e_t can be adjusted instantaneously against wage changes. The firm's period optimization problem then can be written as follows:

$$\max_{K_t, u_t, e_t} \quad \left[Z_t(u_t K_t)^\alpha (e_t L_t)^{1-\alpha} - w(e_t)L_t - (r_t + \delta u_t^\phi)K_t \right]$$

which yields the following first-order conditions:

$$\alpha \frac{Y_t}{K_t} = r_t + \delta u_t^\phi \tag{D.1}$$

$$\alpha \frac{Y_t}{u_t} = \delta \phi u_t^{\phi-1} K_t \tag{D.2}$$

$$(1-\alpha)\frac{Y_t}{e_t} = w'(e_t)L_t \tag{D.3}$$

Combining equations (D.1) and (D.2), and that at the steady state $u = 1$ yields:

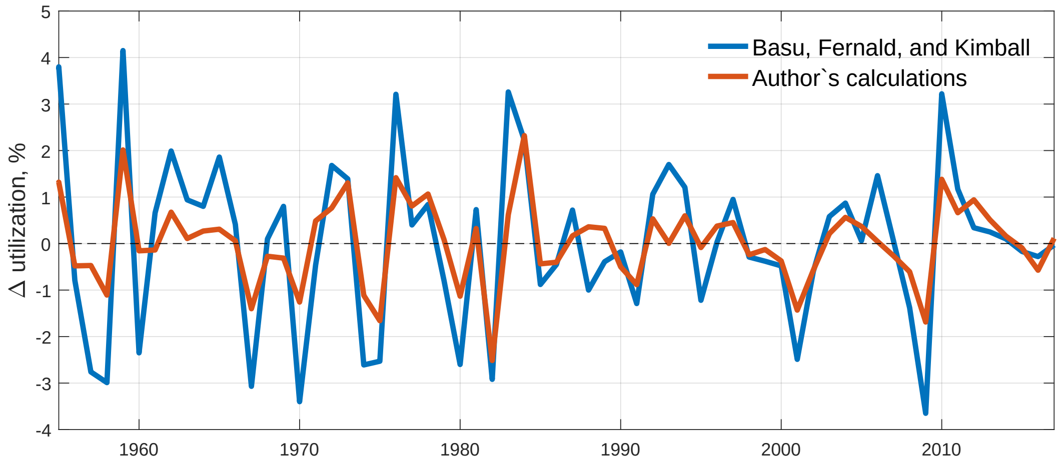
$$u_t = \left(\frac{Y_t/K_t}{Y/K} \right)^{\frac{\delta}{r+\delta}} \tag{D.4}$$

where Y/K is the steady state capital-to-output ratio. Turning to households, they solve the following optimization problem:

$$\max_{\{C_{t+j}, L_{t+j}, e_{t+j}\}_{j=0}^\infty} \quad \mathbb{E}_t \sum_{j=0}^\infty \beta^j \left(\left(C_t - \frac{L_t^{1+\epsilon}}{1+\epsilon} - \frac{e_t^{1+\psi}}{1+\psi} \right)^{1-\sigma} - 1 \right) / (1-\sigma) \quad \text{s.t.} \quad C_t \leq w(e_t)L_t$$

The two margins of labor supply enter the utility function separately. The form of the utility function implies no wealth effect in labor supply. This assumption matches the utility function choice in the general equilibrium model. Moreover, the wealth effect on labor effort is likely to be muted at annual frequency of the data. The first-order condition with respect to

Figure 26: US factor utilization



Note: annual changes in U.S. factor utilization according to (1) Imbs (1999) methodology (author's calculations) and (2) Basu et al. (2006) methodology (annual data from https://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-tfp). Correlation between the two measures = 0.82

labor effort is then the following:

$$w'(e_t)L_t = \frac{u'_{e_t}}{u'_{C_t}} = e_t^{\psi} \tag{D.5}$$

Now, to proceed let me make two assumptions regarding the utility function. First, the labor effort enters the utility function Combining equations (D.5) and (D.3), and assuming the steady state effort $e = 1$ yields:

$$e_t = \left(\frac{Y_t}{Y}\right)^{\frac{1}{1+\psi}} \tag{D.6}$$

Equations (D.4) and (D.6) are used to construct measures of capital and labor utilization. The steady-state values of output, consumption, and capital are determined using a one-sided HP filter with a smoothing parameter of 100, as common in the business cycle analysis. I set the parameter that governs elasticity of effort with respect to wage to the average value across OECD countries according to Imbs (1999): $\psi = 0.1$, although the results are robust to different values of this parameter. I set the two remaining parameters to $r = 0.04$ and $\delta = 0.1$, standard values in the RBC literature (annual calibration). The total utilization component of the Solow residual then equals to $u_t^{\alpha_t} e_t^{1-\alpha_t}$, where I use the time-varying labor share from Feenstra et al. (2015). As a validation exercise, I compare the resulting changes in factor utilization for the U.S. with the widely-used measure based on Basu et al. (2006) methodology. As figure 29 demonstrates, the two series exhibit a strong correlation.

D.2 Housing market equilibrium

For illustrative purposes, I linearize equilibrium conditions of the housing market around the deterministic steady state at which the collateral constraint binds. The housing market equilibrium is determined by the following households demands (written in terms of stationary variables) and the market clearing condition:

$$
\begin{aligned}
p_t^h &= \mathbb{E}_t\left(\Lambda_{t,t+1}^S p_{t+1}^h g_{t+1}\right) + \kappa\vartheta_t \frac{(h_t^S)^{-\epsilon_h}}{\tilde{\lambda}_t^S} \\
p_t^h &= \mathbb{E}_t\left(\Lambda_{t,t+1}^B p_{t+1}^h g_{t+1}\right) + \kappa\vartheta_t \frac{(h_t^B)^{-\epsilon_h}}{\tilde{\lambda}_t^B} + \chi_t(1-\rho_B)mp_t^h \\
1 &= h_t^S + h_t^B
\end{aligned}
$$

where $p_t^h = \frac{P_t^h}{N_t}$ and $\tilde{\lambda}_t^h = \lambda_t^h N_t^\sigma$. The above equations are linearized around the deterministic steady state using sans-serif font to denote percentage deviations from the steady state (i.e. $\mathsf{x}_t = \frac{x_t - x}{x}$):

$$
\begin{aligned}
\mathsf{p}_\mathsf{t}^\mathsf{h} &= \Lambda^S g\,\mathbb{E}_t\left(\mathsf{\Lambda}_{\mathsf{t,t+1}}^\mathsf{S} + \mathsf{p}_{\mathsf{t+1}}^\mathsf{h} + \mathsf{g}_{\mathsf{t+1}}\right) + \frac{\kappa}{\tilde{\lambda}^S p^h (h^S)^{\epsilon_h}}\left(\vartheta_\mathsf{t} - \tilde{\lambda}_\mathsf{t}^\mathsf{S} + \epsilon_h \frac{h^B}{h^S}\mathsf{h}_\mathsf{t}^\mathsf{B}\right) \\
\mathsf{p}_\mathsf{t}^\mathsf{h} &= \Lambda^B g\,\mathbb{E}_t\left(\mathsf{\Lambda}_{\mathsf{t,t+1}}^\mathsf{B} + \mathsf{p}_{\mathsf{t+1}}^\mathsf{h} + \mathsf{g}_{\mathsf{t+1}}\right) + \frac{\kappa}{\tilde{\lambda}^B p^h (h^B)^{\epsilon_h}}\left(\vartheta_\mathsf{t} - \tilde{\lambda}_\mathsf{t}^\mathsf{B} - \epsilon_h \mathsf{h}_\mathsf{t}^\mathsf{B}\right) + \chi(1-\rho_B)m(\chi_\mathsf{t} + \mathsf{p}_\mathsf{t}^\mathsf{h}) \\
\mathsf{h}_t^S &= -\frac{h^B}{h^S}\mathsf{h}_t^B
\end{aligned}
$$

Given other general equilibrium outcomes, the two demand curves along with the market clearing condition determine the current housing price p_t^h and its quantity held by borrowers and savers, h_t^B and h_t^S respectively, in terms of percentage deviations from the deterministic steady state.

Housing demands can be further simplified by substituting linearized first order conditions with respect to bonds for borrowers and savers, equations 12 and 5 in the main text. The original FOCs are as follows:

$$
\begin{aligned}
\mathbb{E}_t\left(\Lambda_{t,t+1}^S \frac{1+r_t}{\Pi_{t+1}}\right) &= 1 \\
\mathbb{E}_t\left(\Lambda_{t,t+1}^B \frac{1+r_t-\rho_B\chi_{t+1}}{\Pi_{t+1}}\right) &= 1-\chi_t
\end{aligned}
$$

Denote the gross real interest rate as $R_t = \frac{1+r_{t-1}}{\Pi_t}$. Linearizing around the deterministic steady state where the collateral constraint binds and simplifying taking into account that

$\chi = \frac{\beta^S - \beta^B}{\beta^S} \frac{\Pi}{\Pi - \beta_B \rho_B g^{-\sigma}}$ and $R = g^\sigma / \beta^S$ one can get:

$$
\begin{aligned}
\mathbb{E}_t \, \mathsf{\Lambda}^{\mathsf{S}}_{\mathsf{t,t+1}} &= -\,\mathbb{E}_t \, \mathsf{R}_{\mathsf{t+1}} \\
\mathbb{E}_t \, \mathsf{\Lambda}^{\mathsf{B}}_{\mathsf{t,t+1}} &= -\,\mathbb{E}_t \, \mathsf{R}_{\mathsf{t+1}} - \underbrace{A^B_{\Lambda 1} \mathsf{\chi}_{\mathsf{t}} + A^B_{\Lambda 2} \, \mathbb{E}_t (\mathsf{\chi}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \mathsf{\Pi}_{\mathsf{t+1}})}_{\text{Collateral constraint wedge}}
\end{aligned}
$$

where $A^B_{\Lambda 1} = \frac{\chi}{1-\chi}$ and $A^B_{\Lambda 2} = \left(\frac{R\Pi}{\rho_B \chi} - 1 \right)^{-1}$ are positive constants. Finally, substituting this result into the linearized housing demand delivers the final expressions:

$$
\mathsf{p}^{\mathsf{h}}_{\mathsf{t}} = A^S_{h1} \mathsf{h}^{\mathsf{B}}_{\mathsf{t}} + A^S_{h2} \mathsf{\vartheta}_{\mathsf{t}} - A^S_{h2} \tilde{\mathsf{\lambda}}^{\mathsf{S}}_{\mathsf{t+1}} + A^S_{h3} \, \mathbb{E}_t \left(\mathsf{p}^{\mathsf{h}}_{\mathsf{t+1}} + \mathsf{g}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} \right) \tag{D.7}
$$

$$
\mathsf{p}^{\mathsf{h}}_{\mathsf{t}} = -A^B_{h1} \mathsf{h}^{\mathsf{B}}_{\mathsf{t}} + \underbrace{A^B_{h2} \mathsf{\vartheta}_{\mathsf{t}}}_{\text{Pref. shock}} - \underbrace{A^S_{h2} \tilde{\mathsf{\lambda}}^{\mathsf{B}}_{\mathsf{t+1}}}_{\text{Wealth effect}} + \underbrace{A^B_{h3} \, \mathbb{E}_t \left(\mathsf{p}^{\mathsf{h}}_{\mathsf{t+1}} + \mathsf{g}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} \right)}_{\text{Next-period discounted return}} - \underbrace{A^B_{h4} \mathsf{\chi}_{\mathsf{t}} + A^B_{h5} \, \mathbb{E}_t (\mathsf{\chi}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \mathsf{\Pi}_{\mathsf{t+1}})}_{\text{Collateral constraint wedge}} \tag{D.8}
$$

where $A^S_{h1} = \epsilon_h \frac{h^B}{h^S} A^S_{h2}$, $A^S_{h2} = \frac{\kappa}{\tilde{\lambda}^S p^h (h^S)^{\epsilon_h}}$, $A^S_{h3} = g^{1-\sigma} \beta^S$; and $A^B_{h1} = \epsilon_h A^B_{h2}$, $A^B_{h2} = \frac{\kappa}{\tilde{\lambda}^B p^h (h^B)^{\epsilon_h} (1-(1-\rho_B) m \chi)}$, $A^B_{h3} = \frac{g^{1-\sigma} \beta^B}{1-(1-\rho_B) m\chi}$, $A^B_{h4} = A^B_{\Lambda 1} A^B_{h3} - \frac{(1-\rho_B) m\chi}{1-(1-\rho_B) m\chi}$, $A^B_{h5} = A^B_{\Lambda 2} A^B_{h3}$ are positive constant.

D.3 Equity market equilibrium

For illustrative purposes, I linearise equilibrium conditions of the equity market around the deterministic steady state at which the collateral constraint binds. The dynamics of the equity market that finances innovation in determined by households demand, equation (14) and the blueprint price p^b, determined by equation (25), along with the free-entry condition that equalizes the firm values and the blueprint price (entry cost):

$$
\begin{aligned}
v_t &= (1 - \delta_N) \, \mathbb{E}_t \left(\Lambda^B_{t,t+1} (d_{t+1} + v_{t+1}) \right) \\
\phi_t p^b_t &= 1 + AC_{S,t} + AC'_{S,t} S^i_t - \mathbb{E}_t \left(\Lambda^B_{t,t+1} AC'_{S,t+1} S^i_{t+1} \right) \\
v_t &= p^b_t
\end{aligned}
$$

To simplify derivations, abstract from adjustment costs in innovation spending ($\psi_N = 0$). Using the definition of the time-varying innovators productivity ϕ_t, equation (24), the system can be simplified as follows:

$$
\begin{aligned}
v_t &= (1 - \delta_N) \, \mathbb{E}_t \left(\Lambda^B_{t,t+1} (d_{t+1} + v_{t+1}) \right) \\
v_t &= \phi^{-1} s_t^{1-\rho}
\end{aligned}
$$

Taking into account that $\mathbb{E}_t \mathsf{\Lambda}^{\mathsf{B}}_{\mathsf{t,t+1}} = -\mathbb{E}_t \mathsf{R}_{\mathsf{t+1}} - A^B_{\Lambda 1}\mathsf{\chi}_{\mathsf{t}} + A^B_{\Lambda 2}\,\mathbb{E}_t(\mathsf{\chi}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \mathsf{\Pi}_{\mathsf{t+1}})$, the linearized counterparts of the above conditions are:

$$\mathsf{v}_{\mathsf{t}} = \underbrace{\mathbb{E}_t\left(A_{v1}\mathsf{d}_{\mathsf{t+1}} + A_{v2}\mathsf{v}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}}\right)}_{\text{Discounted next-period return}} - \underbrace{A^B_{\Lambda 1}\mathsf{\chi}_{\mathsf{t}} + A^B_{\Lambda 2}\,\mathbb{E}_t(\mathsf{\chi}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \mathsf{\Pi}_{\mathsf{t+1}})}_{\text{Collateral constraint wedge}} \tag{D.9}$$

$$\mathsf{v}_{\mathsf{t}} = (1-\rho)\mathsf{s}_{\mathsf{t}} \tag{D.10}$$

where $A_{v1} = \frac{d}{v+d}$, $A_{v2} = \frac{v}{v+d}$, $A^B_{\Lambda 1} = \frac{\chi}{1-\chi}$, and $A^B_{\Lambda 2} = \left(\frac{R\Pi}{\rho_B \chi} - 1\right)^{-1}$ are positive constants

D.4 Marginal utility of consumption dynamics

Start with linearized first order conditions with respect to bonds for borrowers and savers, described in the previous subsections and note that households stochastic discount factor can be expressed as $\mathbb{E}_t \mathsf{\Lambda}^{\mathsf{H}}_{\mathsf{t,t+1}} = \mathbb{E}_t \tilde{\mathsf{\lambda}}^{\mathsf{H}}_{\mathsf{t+1}} - \tilde{\mathsf{\lambda}}^{\mathsf{H}}_{\mathsf{t}} - \sigma \mathsf{g}_{\mathsf{t+1}}$, $H \in \{S, B\}$

$$\mathbb{E}_t\, \mathsf{g}_{\mathsf{\lambda}^{\mathsf{S}}_{\mathsf{t+1}}} = \mathbb{E}_t \tilde{\mathsf{\lambda}}^{\mathsf{S}}_{\mathsf{t+1}} - \tilde{\mathsf{\lambda}}^{\mathsf{S}}_{\mathsf{t}} = -\mathbb{E}_t \mathsf{R}_{\mathsf{t+1}} + \sigma \mathsf{g}_{\mathsf{t+1}} \tag{D.11}$$

$$\mathbb{E}_t\, \mathsf{g}_{\mathsf{\lambda}^{\mathsf{B}}_{\mathsf{t+1}}} = \mathbb{E}_t \tilde{\mathsf{\lambda}}^{\mathsf{B}}_{\mathsf{t+1}} - \tilde{\mathsf{\lambda}}^{\mathsf{B}}_{\mathsf{t}} = \underbrace{-\mathbb{E}_t \mathsf{R}_{\mathsf{t+1}}}_{\text{Real interest rate}} + \underbrace{\sigma \mathsf{g}_{\mathsf{t+1}}}_{\text{Productivity growth}} - \underbrace{A^B_{\Lambda 1}\mathsf{\chi}_{\mathsf{t}} + A^B_{\Lambda 2}\,\mathbb{E}_t(\mathsf{\chi}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \mathsf{\Pi}_{\mathsf{t+1}})}_{\text{Collateral constraint wedge}} \tag{D.12}$$

where $A^B_{\Lambda 1} = \frac{\chi}{1-\chi}$ and $A^B_{\Lambda 2} = \left(\frac{R\Pi}{\rho_B \chi} - 1\right)^{-1}$ are positive constants.

In frictionless economy that exhibits growth the dynamics of marginal utility of consumption depends not only on the expected real interest rate but also on growth expectations.

D.5 Aggregate welfare cost of the crisis

Recall the lifetime utility of a household $H \in \{S, B\}$:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta_H^j \left(U(C^H_{t+j}, L^H_{t+j}) + \kappa_t \vartheta_t G(h^H_{t+j})\right), \quad \text{where}$$

$$U(C^H_t, L^H_t) = \left(\left(C^H_t - \Upsilon_t \frac{(L^H_t)^{1+\epsilon_L}}{1+\epsilon_L}\right)^{1-\sigma} - 1\right) / (1-\sigma)$$

$$G(h^H_t) = \kappa_t \vartheta_t \frac{(h^H_t)^{1-\epsilon_h} - 1}{1-\epsilon_h}$$

Period utilities can be rewritten in terms of stationary variables and the stock of knowledge N_t as follows: $U(c_t^H, L_t^H) = N_t^{1-\sigma}\left(\left(c_t^H - \upsilon_t \frac{(L_t^H)^{1+\epsilon_L}}{1+\epsilon_L}\right)^{1-\sigma} - 1\right)/(1-\sigma)$ and $G(h_t^H) = N_t^{1-\sigma}\kappa\vartheta_t \frac{(h_t^H)^{1-\epsilon_h}-1}{1-\epsilon_h}$. Lifetime utility of each household then can be expressed recursively in terms of stationary variables and productivity growth rates:

$$\mathbb{W}_t^H = \left(\left(c_t^H - \upsilon_t \frac{(L_t^H)^{1+\epsilon_L}}{1+\epsilon_L}\right)^{1-\sigma} - 1\right)/(1-\sigma) + \kappa\vartheta_t \frac{(h_t^H)^{1-\epsilon_h} - 1}{1-\epsilon_h} + \beta^H \mathbb{W}_t^H g_{t+1}^{1-\sigma} \tag{D.13}$$

Finally, the aggregate welfare then is the weighted sum of welfare of savers and borrowers $\mathbb{W}_t = \gamma_B \mathbb{W}_t^B + \gamma_S \mathbb{W}_t^S$. The baseline case assumes that each of the types of households is of the same mass: $\gamma_B = \gamma_S = 0.5$.

The aggregate lifetime utility of households across different scenarios is calculated numerically using the second-order approximation of the model. As common in the literature, I compare the welfare loss/gain across different scenarios by calculating the equivalent variation in steady-state consumption: the percentage by which the steady-state consumption of households would have to be changed in order to achieve the same welfare as in the scenario of interest. Formally, for household H the welfare loss/gain in steady-state consumption units $\Delta_{\mathbb{H}}$ is calculated as $\mathbb{W}_t^H = \mathbb{W}^H((1-\Delta_{\mathbb{W}})c^H, L^H, h^H)$, where $\mathbb{W}_t^H$ is the welfare of the household under the scenario of interest and $\mathbb{W}^H$ is its steady-state welfare.