Housing market cycles, productivity growth, and household debt *

Dmitry Brizhatyuk[†]

April 7, 2021

(click here for the latest version)

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. 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 the collateral constraint to bind and trigger deleveraging. The 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.

*First draft: May 2019. I cannot thank enough Fabio Ghironi for his constant support and encouragement. This work also benefited from discussions with Yu-chin Chen, Tom Holden, Levis Kochin, Rory Mullen, Mu-Jeung Yang, as well as seminar participants at the University of Washington Seattle, University of Surrey, Moody's Analytics, EAA Annual Congress 2020.

†Moody's Analytics, One Canada Square, Canary Wharf, London E14 5AB, UK. dmitry.brizhatyuk@gmail.com, http://dbrizhatyuk.github.io

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 the 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 relationship between housing market cycles, household debt, and total factor productivity (TFP) growth in a 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 the level of GDP in the medium run. A growth accounting decomposition suggests that this persistent decline is primarily driven by a slowdown in TFP growth. Quantitatively, these effects are sizable. For instance, an average housing crash in my sample is associated with a decline in the TFP level of around 2% a decade after the onset of the event. These results are not driven by the global financial crisis or other systemic financial crises that sometimes coincide with housing market crashes.

The cross-country results are further corroborated by the evidence from the 2007 – 2010

[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 homeownership 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).

housing market crash in the US. In a cross-section of metropolitan statistical areas (MSAs), I identify the persistent effect of the crash 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 resulting elasticity of cumulative 2007 – 2017 labor productivity growth to the 2007 – 2010 house prices decline is from 0.12 to 0.32, the range of values consistent with the results of the cross-country analysis. 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 perform counterfactuals. The model combines elements from the literature on deleveraging in a two-agent environment (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 empirical evidence. First, the persistent decline in TFP following housing market crashes motivates the inclusion of the endogenous growth mechanism. Second, the strong empirical comovement between productivity growth, household debt, and house prices, motivates my focus on household mortgage debt. Since my focus is on residential property, I abstract from the role of structures in production. For simplicity, I also abstract from construction assuming that housing, like land, is in fixed supply. As documented by Davis and Heathcote (2007), house price fluctuations are primarily driven by changes in residential land prices. Finally, as in standard quantitative macro models, the inclusion of physical capital as a factor of production, subject to endogenous utilization, improves the ability of the framework to replicate the data.

Within this framework, I explore the aggregate effects of household deleveraging triggered by an unanticipated house price decline. 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.[3] When the preexisting level of debt is sufficiently high, negative housing 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 erodes the economys capacity as it slows the pace of capital and firm-creation investment. The shock thus acts as an aggregate demand shock in the short run, and as an aggregate supply shock in the medium run.

The calibrated model is successful in accounting for the empirical comovement between aggregate variables during 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 study. I also directly use the estimated empirical comovement of macroeconomic variables during housing market crashes to discipline several quantitative parameters 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.

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 house price shock causes the collateral constraint to bind and triggers deleveraging.

[3] For example, Kaplan et al. (2020) argue that demand-side factors, but not changes in credit conditions, were the dominant force behind the latest U.S. housing market boom-and-bust cycle. See also results of Guerrieri and Iacoviello (2017) and Liu et al. (2013), among others.

The resulting weak demand then exacerbates the decline in borrowers housing wealth 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 with two policy experiments. First, I explore the sensitivity of the aggregate welfare cost of the house price decline scenario to parameters of the Taylor rule. Both in the baseline model and in the counterfactual without endogenous growth, the welfare cost is strictly decreasing in the Taylor rule response to cyclical changes in output, but not inflation. Under the baseline calibration, the welfare cost in the baseline economy is 150% larger than in the counterfactual without endogenous growth. However, this welfare difference decreases by an order of magnitude in scenarios with stronger Taylor rule response to cyclical changes output, other things equal. In the second experiment, I explore the effects of a lump-sum transfer from savers to borrowers: a debt forgiveness program. Although this policy fails to curb the house price decline and deleveraging, it is effective in tempering the short-run decline in consumption, investment, and innovation spending. As such, it alleviates the persistent post-deleveraging decline in output and improves the welfare of both borrowers and savers.

Related literature My cross-country analysis adds to the existing empirical literature on the real effects of financial and asset market cycles.[4] The event study is closest to Jordà et al. (2015), who documents 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 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 of aggregate variables and identify their potential drivers.

My analysis of US metropolitan statistical areas also relates to the literature on the 2006-09 US housing market crash that demonstrates the quantitatively important relationship between households' net worth decline and reductions in consumption and local employment (Mian et al. 2013, Mian and Sufi 2014).[5] I demonstrate that the implications of the housing market's crash for the US economy extend far beyond the contemporaneous effect. The legacy of the crash lingers to this day.

Finally, this paper relates to the broader literature studying the nexus between the housing

[4] 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).

[5] Andersen et al. (2014) and Bunn et al. (2015) identify similar patterns in the data from Denmark and the UK 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.

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 house 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).[6]

This paper theoretically relates to several bodies of 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.[7] Differently from this literature, however, the borrowing limit is not exogenous, but tied to the borrowers housing wealth determined in general equilibrium. This feature connects the paper to the literature on the macroeconomic effects of home equity-based borrowing started by Iacoviello (2005).[8] Treating the borrowing limit as endogenously determined allows to account for the amplification through the two-way interactions between deleveraging, borrowers net worth, and economic activity. This effect is state-dependent, shaped by the policy response, and very important quantitatively.

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.[9] Much of the recent theoretical literature on this topic builds on the seminal contribution of Comin and Gertler (2006).[10] In particular, large contractions and slow recoveries in many countries after the global financial crisis have motivated research on the role of endogenous growth and financial shocks in generating such persistence.[11] So far, the existing literature has either focused

[6] 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.

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

[8] 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).

[9] 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.

[10] 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), among others.

[11] Fernald et al. (2017) and Gordon (2015) point out 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 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

on financial frictions that directly affect the financing of innovations (Queralto 2019, Guerron-Quintana and Jinnai 2019, Ikeda and Kurozumi 2018) or remained agnostic about the source of the financial shock altogether, 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.[12]

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 housing market cycle in the US.[13] My contribution is to show, both empirically and theoretically, that this asymmetry extends to productivity growth.

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, the ability of the model to account for the empirical evidence, and explores the key channels driving the dynamics. Section 5 draws implications for monetary and fiscal policy. Section 6 concludes.

2 Empirical evidence

This section studies the macroeconomic effects of housing price shocks. My main interest is whether housing market boom and bust cycles are systematically associated with subsequent slower productivity growth. To this end, I construct an unbalanced panel of macroeconomic

global financial crisis has accelerated an existing trend.

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

[13] 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), among others. 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.

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, see Appendix A. 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). Real house price indices combine the data from BIS, Dallas FED, OECD, and Jorda et al. (2016) Macrohistory databases. I also 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, see Appendix D.1 for details.[14] Finally, I take a closer look at a cross-section of US metropolitan statistical areas during the latest US housing market crash, where data availability allows me to make a stronger statement on the causal relationship between productivity growth and house price decline.

2.1 Panel VAR

I first use a panel VAR to characterize the comovement between house prices, household debt, and TFP. 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 model also includes country fixed effects to account for time-invariant cross-country heterogeneity.

I identify housing price 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, the identified house price shocks are orthogonal to household credit shocks and do not have a contemporaneous effect on the real economy, which rules out more fundamental shocks. As such, these shocks can be interpreted as housing demand shocks.

Figure 3 presents responses to a 1% positive house price shock. This shock is contemporaneously associated with an increase in household debt and no significant effect on the utilization-adjusted TFP. Over time both the house price index and the household debt-to-GDP ratio revert back towards their initial levels. In the medium run, this boom-and-bust

[14] See other applications of the Imbs (1999) correction in Taylor et al. (2020) and Levchenko and Pandalai-Nayar (2018). 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, which is infeasible on a cross-country scale due to data limitations. However, I show that US annual factor utilization growth implied by my calculations closely follows the estimate based on Basu et al. (2006) methodology.

dynamics predicts a persistent decrease in the level of TFP, which falls by as much as 0.06% 15 years after the initial 1% positive house price shock. This is a sizable effect considering the magnitude of major 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 an equally-sized acceleration in productivity growth.

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 these periods the house price dynamics is more likely to be an important independent factor affecting the macroeconomy. Moreover, the relation between house prices and economic activity is likely to be asymmetric and state-dependent due to the presence of occasionally binding collateral constraints tied to housing wealth (e.g. Guerrieri and Iacoviello (2017)). As such, 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 the 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 measure of the magnitude of housing market crashes: $\Delta p^{crash}_{i,t} = \log(P_{i,t+2}) - \log(P_{i,t-1})$. For each event in a country i it

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

equals the cumulative house price decline during the first three years from the peak at $t-1$.

I then use the local projections approach of Jordà (2005) to estimate the elasticities of macroeconomic variables to the house price decline using the following cross-country panel:

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

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 be interpreted as elasticities of the dependent variable to the house price decline over time, conditional on the set of controls described below.

The baseline specification includes country and year fixed effects, α_i^h and α_t^h, and a variety of country-level controls $X_{i,t}$. The set of controls include 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 comovement 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 1.5% decline in house price is associated with a decline in consumption larger than output (about -0.3% and -0.2% respectively) and a -0.7% decline in investment. Second, the decline in economic activity is associated with households deleveraging: the household debt-to-GDP falls by about 0.2%. Finally, the house price decline predicts a very persistent decrease in the levels of output and consumption that extends beyond the conventional duration of business cycles.[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 beyond 10 years after the peak of a housing market cycle. The elasticity of TFP to the house price decline from the peak is quantitatively close to the one in the panel VAR of the previous section: a 1% on-impact house price decline is associated with a 0.1% fall in utilization-adjusted TFP in the

[16] King and Rebelo (1999) define the business cycle component as frequencies from 2 to 32 quarters extracted using the Band Pass filter.

medium run.

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.

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

My cross-country analysis highlights that housing market boom-and-bust cycles predict slower future TFP growth. To reinforce this result, I also present evidence of the negative effect of the latest housing market crash on labor productivity growth across US MSAs. The larger cross-sectional dimension of the data along with the availability of instrumental variables for the regional house price growth allows me 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] The second is 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; $\widehat{\Delta p_i^H} = \log(P_{i,2010}^H) - \log(P_{i,2007}^H)$ is the instrumented log difference of the house price index; and X_i' includes MSA-level industry shares of GDP as well as per capita income, both in 2006. The rationale is to address the concern that differences in regional

[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.

productivity growth were driven primarily by sector-specific shocks and/or by the growing regional income polarization. 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, consistent with the results of the cross-country study of housing market crashes. 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.2 gathers some additional results, including first-stage regressions and the analysis of the boom phase of the housing market cycle. The latter shows that the relationship between the house price and labor productivity growth is asymmetric, consistent with the previous discussions. The boom phase of the latest US housing market cycle was not associated with an increase in productivity growth.

3 The model

Analyses of the previous section provide evidence of the negative effect of housing market boom-and-bust cycles on subsequent productivity growth. In this section, I develop a dynamic general equilibrium model that provides a structural interpretation for this evidence. 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. 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". Instead, they can be broadly interpreted as those who have an access to investment opportunities and need external funding, which is constrained by the debt limit. In my model, this assumption makes holders of capital and equity levered. This setting can be interpreted as a shortcut to a full-fledged financial sector. 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:

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

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.[20]

[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 the 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 bankers problem in Gertler and Karadi (2011).

[20] Jaimovich and Rebelo (2009) suggest a similar preference that allows parameterizing the short-run wealth effect on the labor supply. 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 labor then consists of the forgone output in-home production, and it increases as productivity improvements in the formal sector spill over to home production. To the extent this process takes time, the disutility of labor exhibits inertia.

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 that generates exogenous shifts in housing demand. Finally, the government finances its expenditure by levying lump-sum taxes on savers and borrowers $G_t = T_t^S + T_t^B$.

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:

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

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

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 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), capital depreciation rate is an increasing function of utilization so that capital utilization is endogenous. 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 $P_t^h h_t^B$.[21] 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.[22]

The full program of borrowers takes the following form:

$$\max_{\substack{\{C_{t+j}^B, L_{t+j}^B, h_{t+j}^B, B_{t+1+j}^B,\\ \iota_{t+1+j}, K_{t+1+j}, I_{t+j}, u_{t+j}\}_{j=0}^{\infty}}} \quad \mathbb{E}_t \sum_{j=0}^{\infty} \beta_B^j \left(U(C_{t+j}^B, L_{t+j}^B) + \kappa_t \vartheta_t G(h_{t+j}^B) \right) \quad \text{s.t.}$$

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

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

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

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

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

[21] I do no explicitly model the origins of this constraint. A natural interpretation, however, is that due to the imperfect enforceability of contracts, households borrowing limit is a function of the value of their collateral assets that can be seized by creditors in a case of default. In a narrow sense, m is the maximum loan-to-value (LTV) ratio; but it can also be linked to the degree of the country's financial markets development.

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

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, as discussed in section 4.2.3.

From the first order condition with respect to share holdings ι_{t+1} follows equity demand:

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

Iterating it forward, one gets: $v_t = \mathbb{E}_t \sum_{j=0}^{\infty} \Lambda_{t,t+j}^B (1-\delta_N)^j d_{t+j}$. 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:

$$q_t = \mathbb{E}_t \left(\Lambda_{t,t+1}^B ((1-\delta_{K,t}) q_{t+1} + R_{t+1}^K)\right) \tag{15}$$

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

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

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:

$$W_t = \Upsilon_t (L_t^B)^{\epsilon_L} \tag{18}$$

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.

3.2.1 Production sector

The production sector is populated by perfectly competitive firms operating, similarly to Comin and Gertler (2006), the following production function: $F_t = Z_t \left(\tilde{K}_t^{\alpha} L_t^{1-\alpha}\right)^{1-\xi} X_t^{\xi}$. Firms employ homogeneous labor supplied by both households, $L_t = L_t^S + L_t^B$, 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 measured TFP.

Given input prices, the representative firm maximizes its expected profit stream:

$$\max_{\{x_{t+j}(\omega), L_{t+j}, K_{t+j}\}_{j=0}^{\infty}} \quad \mathbb{E}_t \sum_{j=0}^{\infty} \Lambda_{t,t+j}^{B} \left[p_t^F F_{t+j} - R_{t+j}^K \tilde{K}_{t+j} - W_{t+j} L_{t+j} - \int_0^{N_t} p_{t+j}^x(\omega) x_{t+j}(\omega) d\omega\right]$$

The problem implies the following input demands:

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

$$R_t^K = p_t^F \alpha (1-\xi)\frac{F_t}{\tilde{K}_t} \tag{20}$$

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

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

$$x_t = \left(\frac{A\xi}{\nu}\right)^{\frac{1}{1-\xi}} (p_t^F Z_t)^{\frac{1}{1-\xi}} N_t^{\frac{\nu\xi-1}{1-\xi}} \tilde{K}_t^{\alpha} L_t^{1-\alpha} \tag{21}$$

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

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_t^b. 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: $v_t = p_t^b$.

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 $P_t(j)$ 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. Wholesalers period real profit is $d_t^w(j) = \frac{P_t(j)}{P_t} Y_t(j) - \frac{P_t^F}{P_t} F_t(j) - AC_p(j) - \Gamma$.

Each wholesaler maximizes its profit stream, $\max_{\{P_{t+k}(j)\}_{j=0}^{\infty}} \mathbb{E}_t \sum_{k=0}^{\infty} \Lambda_{t,t+k}^B d_{t+k}^w(j)$, subject to retailers demand $Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\eta} Y_t$. The resulting optimal price is a time-varying markup over the marginal cost $P_t(j) = \mu_t P_t^F$, where the markup is:

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

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: $\max_{\{S_{t+j}^i\}_{j=0}^\infty} \mathbb{E}_t \sum_{j=0}^\infty \Lambda_{t,t+j}^B \left(p_{t+j}^b \phi_{t+j} S_{t+j}^i - (1 + AC_{S,t+j}) S_{t+j}^i\right)$. 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.[23] 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-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.

[23] 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.

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 (ZLB):

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

Parameters $\phi_\Pi > 0$ and $\phi_Y \geq 0$ and govern the policy response to inflation and changes in GDP relative to the BGP; $\rho_r \in [0, 1)$ determines the degree of interest rate smoothing.

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, 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: $GDP_t = Y_t - N_t \frac{x_t}{A} = C_t^S + C_t^B + I_t + p_t^b N_{e,t} + AC_{p,t} + AC_{S,t}$.

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 trend growth fluctuations.

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 (3-31) 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 ($\vartheta_t, Z_t$). 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 a quarterly frequency. To the extent possible, the parameter choice is informed either directly by the data or by the existing estimates in the literature. Table 4 summarizes parameters of the baseline model.

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 set β^S to replicate the steady-state annual real interest rate of 4%, which implies $\beta^S = 0.9968$. The borrowers' discount factor is then set to be lower than that of savers. 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 set $\beta^B = 0.9918$, implying the difference between savers' and borrowers' discount factors in line with the existing literature, for instance, the estimate of Guerrieri and Iacoviello (2017). Next, I set the Frisch elasticity of labor supply to $1/\epsilon_L = 1$. The choice of the housing demand price elasticity is based on the results of Hanushek and Quigley (1980), who provide estimates 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 the price elasticity to -0.2, implying $\epsilon_h = 5$. 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 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.

4.1.2 Shock process and the solution method

I use the model to study the general equilibrium effects of housing market crashes. The existing literature identifies the important role of demand-side factors in generating realistic swings in house prices. Introducing exogenous disturbances to the weight of housing in the utility function – housing preference shocks – is a common reduced-from way to capture such demand-side factors.[24] Formally, I assume that the weight of housing in the utility function, ϑ_t, is governed by an AR(1) process $\ln(\vartheta_t) = (1 - \rho_\vartheta)\ln(\vartheta) + \rho_\vartheta \ln(\vartheta_{t-1}) + \varepsilon_t^\vartheta$, where ε_t^ϑ is an aggregate housing preference shock.

Although my further analysis focuses on a scenario of an unanticipated house price decline that triggers deleveraging, the model is successful in generating empirically relevant housing market boom-and-bust cycles. Importantly, due to the presence of the occasionally binding collateral constraint, the model captures the asymmetric relationship between house prices and productivity growth highlighted by my panel VAR analysis. Appendix C.1 illustrates a housing market boom-and-bust cycle driven by shifts in beliefs about future housing demand, the main driver of movements in the US house prices around the Great Recession according to Kaplan et al. (2020).

The model features two sources of non-linearities: the occasionally binding collateral constraint of borrowers, and the zero lower bound constraint on the policy rate, which poses a computational difficulty since the model cannot be solved using standard perturbation methods. To tackle this problem, I employ the method developed by Holden (2019).[25] This approach provides an alternative to global methods that are most accurate but channeling to implement in models with many state variables. The algorithm is compatible with higher-order approximations and allows to improve the solution accuracy by integrating over future uncertainty following the stochastic extended path algorithm of Adjemian and Juillard (2013). This is an improvement over solution methods such as the Occbin routine of Guerrieri and Iacoviello (2015) that handle occasionally binding constraints in a perfect-foresight, piecewise-linear fashion.

[24] For example, 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. This evidence is corroborated by Guerrieri and Iacoviello (2017), who suggest that about 70% of the consumption decline during the Great Recession in the U.S. can be traced back to housing demand shocks. See also the study of sources and consequences of US housing market fluctuations in Iacoviello and Neri (2010), among others.

[25] The method is implemented in the DynareOBC toolkit, which extends Dynare, Adjemian et al. (2011); available at https://github.com/tholden/dynareOBC

4.1.3 Estimated parameters

I first investigate the ability of 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 at the stochastic steady state 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-projection) and theoretical (model-based) impulse responses, as in Christiano et al. (2005). 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).

Formally, the problem is to minimize the weighted distance between empirical and theoretical IRFs: $\hat{P} = \text{argmin } (\Sigma^{DSGE}(P) - \Sigma^{LP})\ \Omega^{-1}\ (\Sigma^{DSGE}(P) - \Sigma^{LP})'$, 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 a diagonal matrix with the standard deviations of Σ^{LP} on the main diagonal. The minimization problem includes impulse responses of output, consumption, investment, capital, labor, and utilization-adjusted TFP.The resulting estimated borrowing limit inertia is $\rho_b = 0.76$, close to the result of Guerrieri and Iacoviello (2017); adjustment cost parameters for capital and innovation spending are $\psi_N = 0.5$ and $\psi_K = 1$, respectively. The capital utilization parameter is $c_2 = 0.08$, its low value suggests that this component of the model is important for capturing the short-run dynamics of the Solow residual. Finally, the disutility of labor exhibits a significant degree of inertia, $\rho_\Upsilon = 0.925$, implying that the short-run wealth effect in labor supply is weak.

4.1.4 Accounting for the empirical evidence

Overall, the model accounts well for the macroeconomic comovement during housing market crashes. Immediate results of IRF matching are presented on panel (a) of figure 7. One thing worth noting is that the short-run response of labor is stronger than in the data. The empirical response of labor may be underestimated since it's based on the employment-to-population ratio and so does not account for changes in working hours. Panel (b) of figure 7 presents the decomposition of output and TFP dynamics. Consistent with the empirical evidence, the decline in economic activity at medium-run horizons is driven largely by the negative effect on the level of capital stock and TFP. The model also sheds some light on the relative contributions of factors driving measured TFP. The lion's share of the short-run response of the measured TFP is driven by the decrease in capital utilization and the markup distortion, whereas the effect of missing innovation plays the central role during the recovery phase.

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 4.2.3 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.[26] 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 innovation and capital accumulation.

The shock causes inflation to fall in the short run. However, after the acute phase of deleveraging is over, inflation persistently overshoots its steady-state level. Intuitively, this medium-run inflationary effect is driven by a persistent decrease in the capital stock and TFP, both of which push marginal costs up. The combination of falling inflation and output in the short run dictates a sharp decrease in the policy rate, which under certain conditions may cause the ZLB to bind and exacerbate the effects of the shock.

4.2 Exploring the mechanism

I identify and illustrate four main channels that shape the general equilibrium response to negative housing demand shocks in my framework when borrowers become credit-constrained.

4.2.1 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

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

the collateral constraint to bind forcing borrowers to reduce spending to meet the lower credit limit. The downward revision in the borrowing limit causes a temporary decrease in the natural rate, determined by the savers stochastic discount factor in a flexible price economy. Under nominal rigidity, however, the real interest rate may fail to adjust accordingly to allow savers to 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 ZLB significantly amplifies the aggregate demand channel. To illustrate it, I append a risk-premium shock a_t to the savers intertemporal optimality condition: $\mathbb{E}_t\left(\Lambda^S_{t,t+1}\frac{1+r_t}{\Pi_{t+1}}\right) = 1 + a_t$. As common in the literature, I use this shock to simulate a situation when the ZBL binds.[27] 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 conditional on the ZLB binding for the first 8 quarters.Panel (b) of figure 9 compares the binding ZLB counterfactual to the baseline simulation. The amplification is driven by a larger decrease in the aggregate demand when the policy rate is constrained by the ZLB. The resulting on-impact contraction in output is around 3 times larger than in the baseline. Moreover, the endogenous productivity growth mechanism drives around 2 times larger loss in output in the medium term.

4.2.2 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 temporarily lower. Moreover, the consumption-smoothing motive of credit-constrained borrowers makes them reduce investment by more than consumption when deleveraging.

[27] 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.

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 ($\psi_S = 10^5$). In this scenario, the measured TFP suffers only a short-lived decline due to a change in capital utilization and the markup distortion. As a result, responses of consumption and output exhibit less persistence.

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 equity supply and demand curves, see appendix D.3 for details:

$$\text{Equity demand: } \mathsf{v_t} = \underbrace{\mathbb{E}_t\left(A_{v1}\mathsf{d_{t+1}} + A_{v2}\mathsf{v_{t+1}} - \mathsf{R_{t+1}}\right)}_{\text{Discounted next-period return}} - \underbrace{A^B_{\Lambda 1}\chi_\mathsf{t} + A^B_{\Lambda 2}\,\mathbb{E}_t(\chi_\mathsf{t+1} - \mathsf{R_{t+1}} - \Pi_\mathsf{t+1})}_{\text{Collateral constraint wedge}} \tag{32}$$

$$\text{Equity supply: } \mathsf{v_t} = A_{v3}\mathsf{s_t} + \underbrace{\phi_N\left(A_{v4}(\mathsf{s_t} + \mathsf{g_{t-1}} - \mathsf{s_{t-1}}) - A_{v5}\,\mathbb{E}_t(\mathsf{s_{t+1}} + \mathsf{g_t} - \mathsf{s_t})\right)}_{\text{R\&D adjustment cost effect}} \tag{33}$$

Given other general equilibrium outcomes, these curves jointly determine the current-period equity price $\mathsf{v_t}$ and the amount of innovation spending financed $\mathsf{s_t}$, . As the second equation illustrates, the equity demand shifts due to a combination of two factors. First and foremost, equity demand is determined by expected returns from firm ownership. In addition, equity demand is distorted when borrowers are credit-constrained, $\chi_t > 0$.

I use the above demand and supply equations to illustrate the determinants of innovation spending dynamics graphically. Panel (b) of figure figure 10 illustrate the equity market equilibrium at $t = 5$ consistent with the baseline simulation. As a result of a series of negative housing preference shocks, borrowers are forced to deleverage and equity demand falls. The equity market equilibrium moves from the steady state (point A) to equilibrium with lower innovation spending (point B). How much of this demand shift is directly due to the effect of binding collateral constraint? The dashed line plots the equity demand curve excluding, in a partial equilibrium sense, the contemporaneous effect of the collateral constraint wedge (point C). Almost a half of the general equilibrium decline in the equity price is directly driven by the collateral effect, with the rest driven by the decline in returns on innovation.

4.2.3 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.*[28] At the core of this channel is the pecuniary externality: credit-constrained borrowers do not internalize the effect of their spending reduction on aggregate housing wealth that ultimately determines their borrowing capacity. The initial deleveraging then exacerbates the damage to borrowers balance sheets and causes further deleveraging.

Panel (a) of figure 11 provides more details on the dynamics of the housing market during the studied scenario. Although the housing preference shock is aggregate and equally affects borrowers and savers, there's a sizable difference in the housing wealth dynamics of the two agents. The reason is that in general equilibrium credit-constrained borrowers decrease their housing demand by more than savers, which results in the reallocation of housing towards savers. In aggregate, this further erodes borrowers' housing wealth and borrowing capacity.

For illustrative purposes, I linearize housing market equilibrium conditions. I use these to further shed light on the housing demand dynamics asymmetry between borrowers and savers. Let the san-serif font denote percentage deviations of variables from the steady state. The resulting linear housing demand curves are the following, see appendix D.2 for details:

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

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

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

Given other general equilibrium outcomes and the aggregate housing preference shock ϑ_{t}, these curves jointly determine the house price p^h_t and the allocation of housing towards borrowers $\mathsf{h}^{\mathsf{B}}_{\mathsf{t}}$. Common factors that shift both demand curves are the aggregate preference shock and changes in the expected next-period return. Demands are also affected by household-specific wealth effects: when the marginal utility of consumption is high, the valuation of housing in consumption units is low, and vice versa. Under the baseline calibration, the wealth effect on the housing demand is small. The asymmetry between borrowers' and savers' housing demands is mainly driven by the effect of binding collateral constraint: the *collateral constraint wedge*. For plausible parameter values, the effect of this wedge on borrowers housing demand is negative:

[28] 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).

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 to illustrate the housing market equilibrium at $t = 15$ of the baseline simulation. A series of negative housing preference shocks causes the housing demand of both borrowers and savers to fall. The market moves from the steady state (point A) to the equilibrium with a lower house price (point B). Importantly, even though the housing demand shock is aggregate and equally affects both agents, in general equilibrium the borrowers housing demand falls by more. As a result, borrowers housing wealth additionally deteriorates because of the housing stock redistribution towards savers. The lion's share of this outcome is driven by the collateral constraint wedge: the dashed line shows, in a partial equilibrium sense, the shift of borrowers demand curve excluding the contemporaneous effect of the collateral constraint wedge (point C).

The above experiment illustrates the quantitatively important role of Fisherian debt deflation in exacerbating the downturn induced by the housing price collapse. In addition, counterfactual simulations in appendix C show that both short- and medium-run dynamics are sensitive to the initial debt-to-GDP ratio of the economy, other factors equal.

4.2.4 Expected income growth channel

The second amplification mechanism 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.

To illustrate this channel, I linearize consumption Euler equations of savers and borrowers, please refer to D.4 for details. Expected growth of marginal utility of consumption can be expressed as follows:

$$\text{Savers } u_c' \text{ growth:} \quad \mathbb{E}_t \, \mathsf{u}'_{\mathsf{c}^{\mathsf{S}}_{\mathsf{t+1}}} - \mathsf{u}'_{\mathsf{c}^{\mathsf{S}}_{\mathsf{t}}} = \quad -\mathbb{E}_t \, \mathsf{R}_{\mathsf{t+1}} \quad + \sigma \, \mathbb{E}_t \, \mathsf{g}_{\mathsf{t+1}} \tag{36}$$

$$\text{Borowers } u_c' \text{ growth:} \quad \mathbb{E}_t \, \mathsf{u}'_{\mathsf{c}^{\mathsf{B}}_{\mathsf{t+1}}} - \mathsf{u}'_{\mathsf{c}^{\mathsf{B}}_{\mathsf{t}}} = \quad \underbrace{-\mathbb{E}_t \, \mathsf{R}_{\mathsf{t+1}}}_{\text{Real interest rate}} \quad + \underbrace{\sigma \, \mathbb{E}_t \, \mathsf{g}_{\mathsf{t+1}}}_{\text{Growth}} - \tag{37}$$

$$\underbrace{-A^B_{\Lambda 1} \chi_{\mathsf{t}} + A^B_{\Lambda 2} \, \mathbb{E}_t (\chi_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \Pi_{\mathsf{t+1}})}_{\text{Collateral constraint wedge}}$$

Productivity growth has a positive effect on the growth of marginal utility of consumption with the magnitude of this effect governed by the elasticity of intertemporal substitution σ. In other words, current consumption depends on future growth expectations. When growth is expected to be slower in the next periods, current consumption decreases. The above equations allow me to illustrate the direct role of expected next-period growth relative to other factors.

Figure 12 plots growth of marginal utility of consumption for borrowers and savers consistent with the baseline simulation. The stark difference between the two agents is due to borrowers' consumption-saving decisions being distorted by the binding collateral constraint. The figure also shows a counterfactual that excludes the direct effect of expected next-period growth. It illustrates the quantitatively significant role of lower expected growth in exacerbating the demand-driven downturn in the short run.[29]

5 Policy scenarios

5.1 Monetary policy

Negative housing demand shocks that trigger deleveraging warrant a stronger focus of monetary policy on output stabilization, especially when productivity growth is endogenous. In section 4.2.1, I discuss that these shocks propagate in the short run similarly to aggregate demand shocks; naturally, their effects are significantly exacerbated when the policy rate is constrained by the ZLB. This section's experiment provides a broader view on the role of the conduct of monetary policy. The experiment is as follows: I evaluate the welfare cost of the house price decline scenario of section 4.1.3 under various parameters of the Taylor rule (27). In addition to the baseline model, I also consider an alternative setting without endogenous growth. As standard in the literature, I compare the welfare change across scenarios by calculating the equivalent variation in the steady-state consumption. Please refer to appendix D.5 for the discussion of welfare calculations.

Figure 13 illustrates the sensitivity of the welfare cost to the Taylor rule sensitivity to inflation (ϕ_π) and cyclical variations of output (ϕ_Y). In all cases, the welfare cost of the house price decline scenario is strictly decreasing in the strength of the policy response to cyclical fluctuations in output. The effect of variations in the policy rate sensitivity to inflation, on the other hand, is ambiguous and can be positive or negative depending on the initial values of the parameters. The endogenous growth mechanism magnifies the welfare loss: under the baseline calibration ($\phi_\pi = 1.5$, $\phi_Y = 0.125$), the welfare loss is more than 2.5 times larger in the economy with endogenous growth, other things equal. However, this gap reduces considerably under a

[29] 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.

policy rule more sensitive to the short-run fluctuations in output. When $\phi_Y = 0.45$, the welfare loss in the economy with endogenous growth is only 30% larger than in the economy without endogenous growth.

5.2 Fiscal policy

In my last experiment, I assess the effectiveness of a debt relief program in mitigating the effects of a housing market crash. Various programs of this kind are often considered during periods of financial instability. For instance, amid the Great Recession in US government has engaged in a $22.61 billion Home Affordable Modification Program to facilitate mortgage restructuring for homeowners who are at risk of foreclosure. Formally, recall that the government finances its expenditure by levying lump-sum taxes on savers and borrowers $G_t = T_t^S + T_t^B$. The debt relief program then involves shifting the tax burden from borrowers to savers by Δ_t.

Figure 14 presents the baseline simulation along with the counterfactual where a transfer Δ_t equivalent to a 0.1% of borrowers steady-state debt burden is conducted at $t = 2$, the transfer is set to be persistent and it phases out at a rate of 10% per quarter. The first observation is that the policy fails to mitigate the house price decline and the resulting household deleveraging. However, a transfer towards credit-constrained borrowers improves the general equilibrium outcome by allowing them to pay off some outstanding debt instead of cutting their consumption and, most importantly, capital investment and innovation spending that determines the longer-term path out of the crisis. It also increases inflation relative to the baseline rendering it especially powerful when monetary policy is constrained by the ZLB in the short run.

The policy lowers the aggregate welfare cost of the house price decline scenario by 17.1% with both borrowers and savers being better-off, by 53.4% and 13.8%, respectively. Even though savers experience a greater decrease in consumption in the short run when financing the policy, they benefit over the longer horizon as the economy maintains a higher level of TFP and capital.

6 Conclusion

Why recoveries from financial crises tend to be slow and incomplete? I contribute to this debate by studying the effects of the housing market boom-and-bust cycles. This paper provides new empirical evidence on the comovement between house prices, household debt, and productivity growth. Both in a cross-country panel and a cross-section of US MSAs, housing market crashes robustly predict a persistent decrease in the productivity level. This effect goes hand in hand with household deleveraging, is quantitatively large, and asymmetric: the boom phase of the cycle is not contemporaneously associated with an equally-sized increase in productivity growth.

These empirical findings are interpreted through the lens of a dynamics general equilibrium model that features borrower and saver households, occasionally binding collateral constraints tied to housing wealth, endogenous growth through forward-looking investment, and nominal rigidity. The model successfully accounts for the empirical comovement between variables and highlights the importance of endogenous innovation in generating empirically relevant persistent effects of collapses in house prices. I highlight the quantitatively important amplification role of the negative feedback loop between household deleveraging, current spending, and future growth. In this framework, a stronger focus of monetary policy on output stabilization can considerably reduce the aggregate welfare cost of the crisis. And so does a fiscal policy intervention that alleviates the debt overhang of credit-constrained borrowers.

The findings of this paper can help inform the debate on the macroeconomic costs of financial cycles. Specifically, my results suggest that the cost of household leveraging-deleveraging cycles can be significantly understated by methods that abstract from the endogenous loss of productivity induced by such crises. This, in turn, provides a rationale for a stronger policy intervention to curb the short-run fall in the aggregate demand and facilitate the orderly transition of the economy to lower credit availability. For example, the paper provides a structural interpretation of self-defeating fiscal consolidations in depressed economies: reductions in deficits that fail to reduce debt-to-GDP ratios because of their negative long-term effects on GDP (Delong and Summers 2012, Fatás and Summers 2018). My findings also have implications for the cost-benefit analysis of policies that react to excess credit growth ex-ante thus preventing crises, "leaning against the wind", relative to the ex-post measures, "mopping up after the crash" (e.g. Gourio et al. 2018). I believe these are promising avenues for further research.

Figure 1: US real per capita GDP [cited on page 2 and 12]

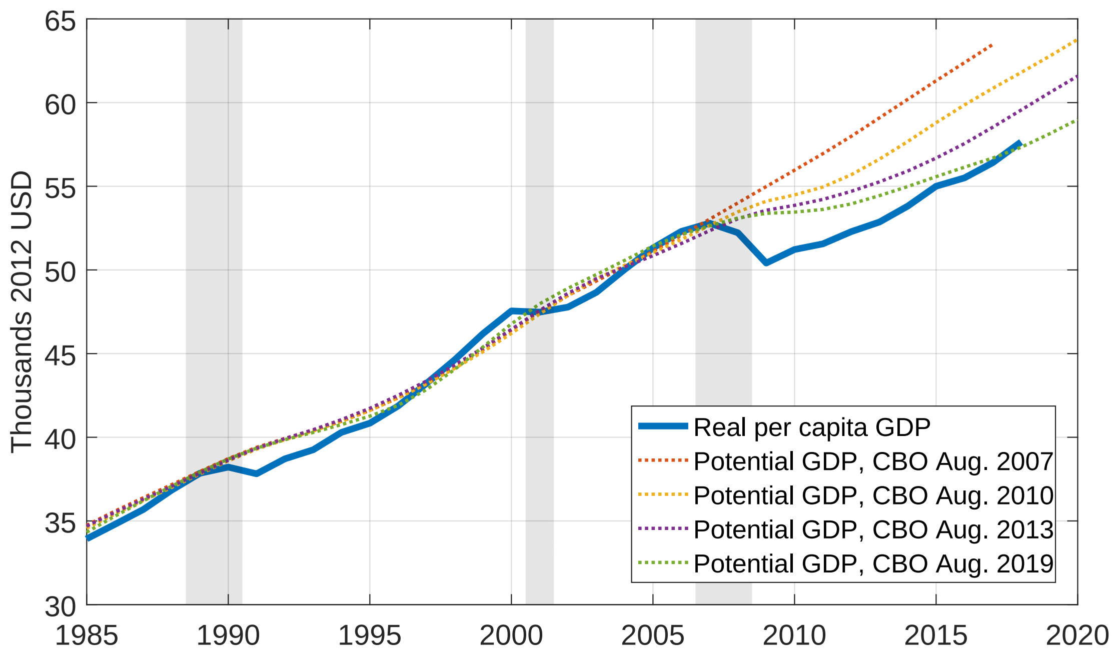


Figure 2: Housing market boom and bust cycles across countries [cited on page 2]

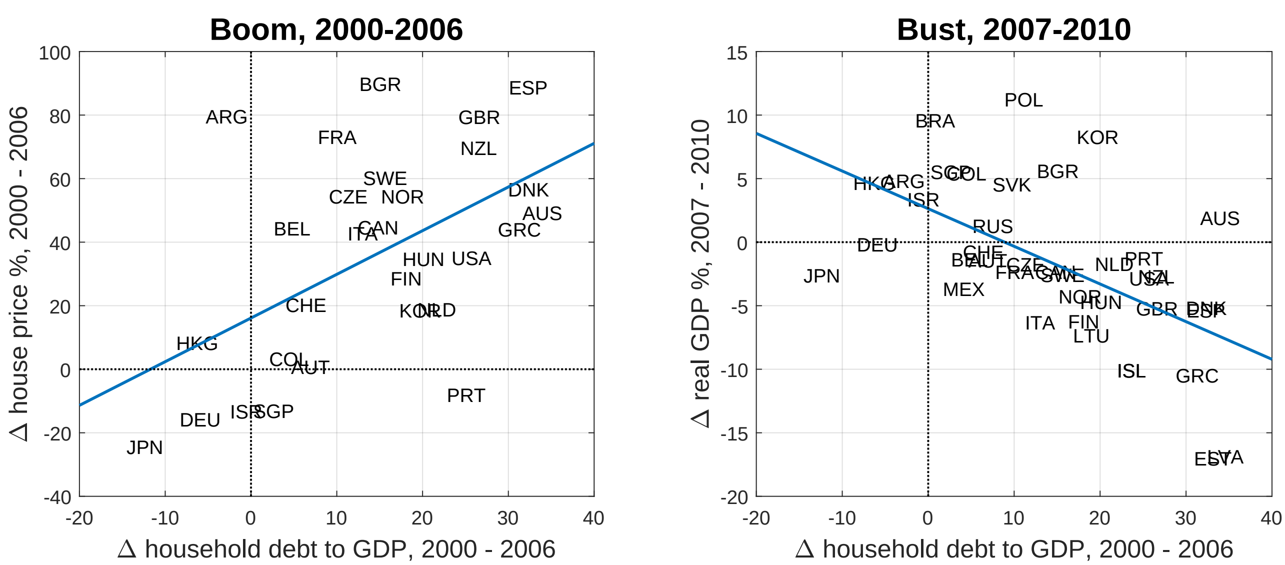
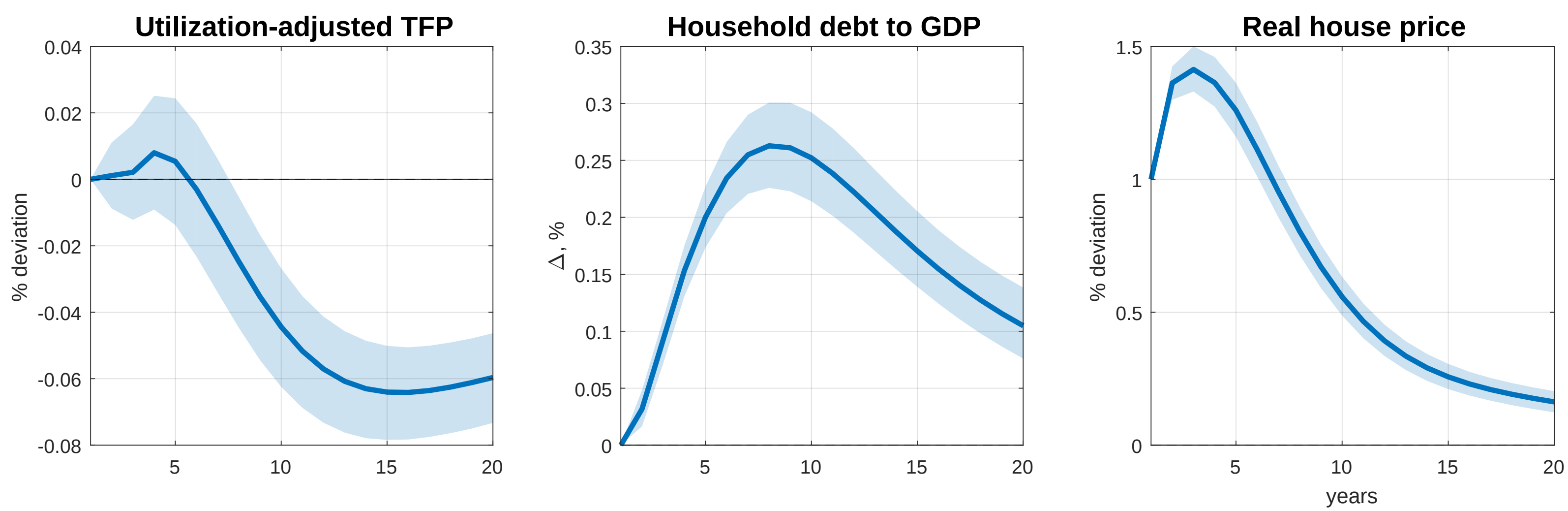


Figure 3: Panel VAR, responses to a house price shock [cited on pages 8]



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

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

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

See details in section 2.1

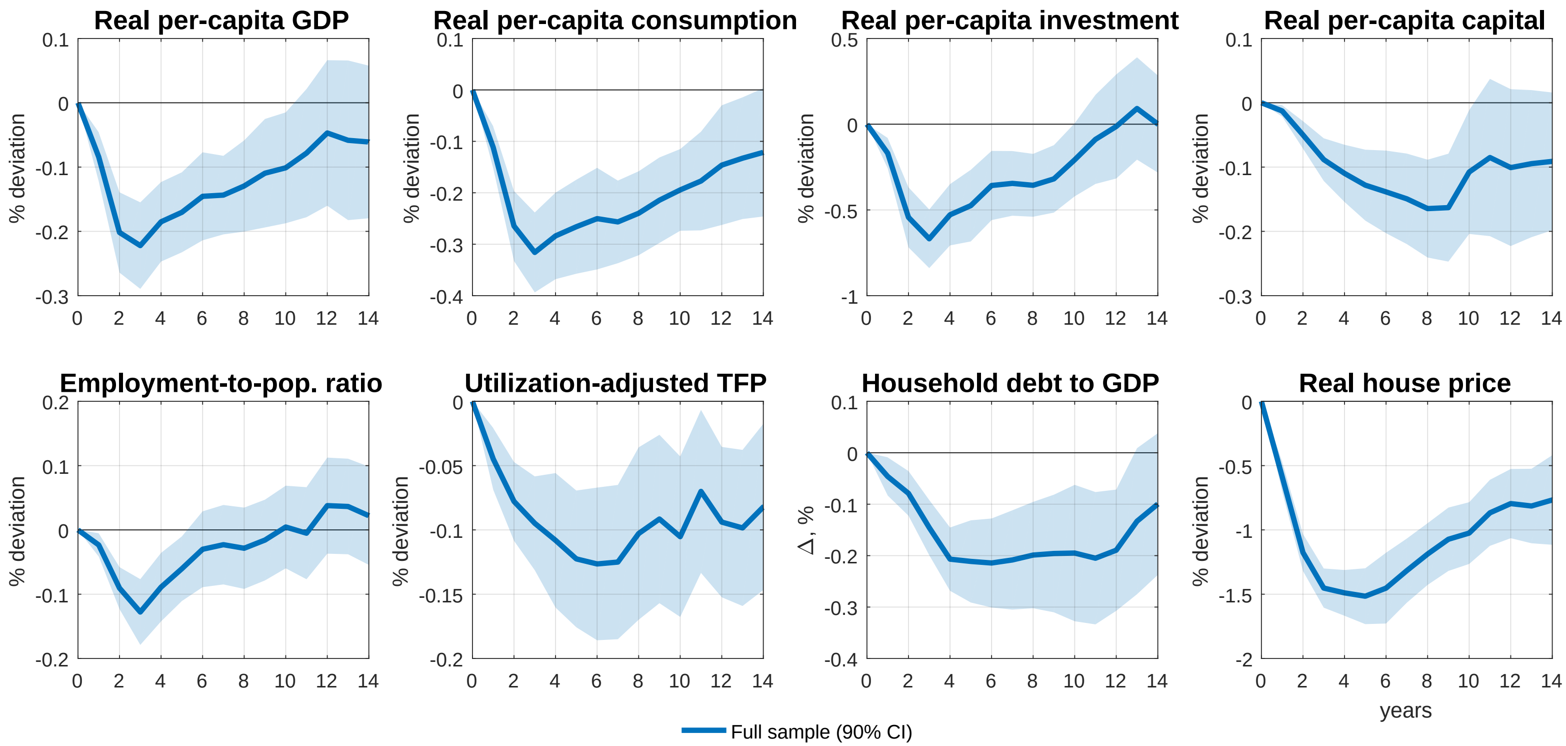
Table 1: Sample of housing market crashes [cited on page 9]

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 10]



Note: cross-country panel, local projections: $\Delta_h y_{i,t+h} = \alpha_i^h + \alpha_t^h + \beta^h \Delta p_{i,t}^{\text{crash}} + X_{i,t}\Gamma + \varepsilon_{it}^h$, where $\Delta_h y_{i,t+h}$ is a cumulative $h-$period growth of the variable of interest; $\Delta p_{i,t}^{\text{crash}}$ is the measure of the severity of the housing market crash that starts at period t; α_i^h and α_t^h are country and year fixed effects, respectively; and $X_{i,t}$ and set of macro controls.

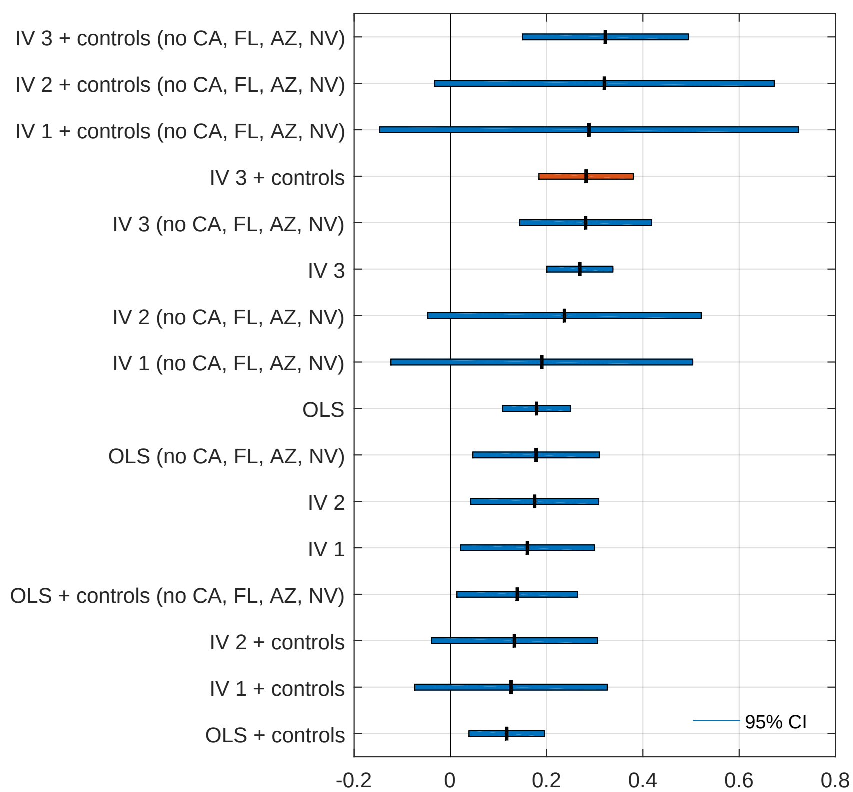
Shaded areas correspond to 90% confidence intervals. Standard errors are clustered at the country level.

See details in section 2.2

Figure 5: 2007 US housing market crash [cited on page 12]

(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: cross-section of US MSAs; IV specification with controls is $\Delta lp_i = \alpha + \eta \widehat{\Delta p_i^H} + X_i'\Gamma + \varepsilon_i$, where $\Delta lp_i = \log(LP_{i,2017}) - \log(LP_{i,2007})$ is growth of labor productivity, defined as real GDP per worker; $\widehat{\Delta p_i^H} = \log(P^H_{i,2010}) - \log(P^H_{i,2007})$ is the instrumented house price growth. Output and employment data is from BEA. House price growth is based on FHFA all-transactions house price indexes. The vector of controls X_i' includes 2006 MSA-level 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 capita personal income. Specifications (5-8) & (13-16) exclude the four states most affected by the housing market crash.

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 13]

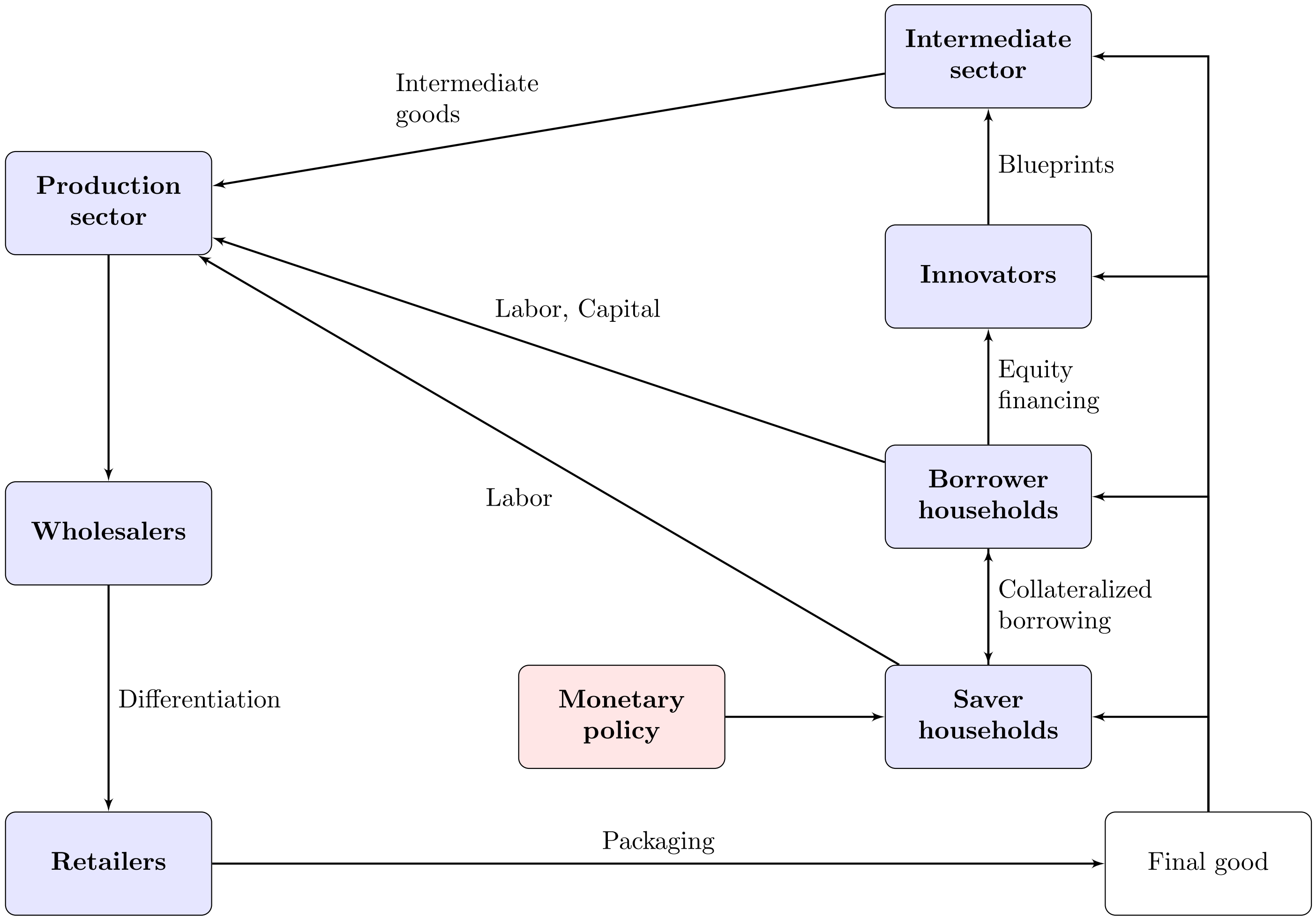


Table 3: Model summary [cited on page 21]

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	$c_t^S + p_t^h(h_t^S - h_{t-1}^S) + \frac{1+r_{t-1}}{\Pi_t}\frac{b_t^S}{g_t} = w_t L_t^S + b_{t+1}^S - T_t^S$
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	$(b_{t+1}^B - \rho_B \frac{b_t^B}{\Pi_t g_t} - (1-\rho_B) m p_t^h h_t^I)\chi_t = 0, \quad \chi_t \geq 0$
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	$p_t^h = \mathbb{E}_t\left(\Lambda_{t,t+1}^P p_{t+1}^h g_{t+1}\right) + \kappa\vartheta_t \frac{(h_t^P)^{\epsilon_h}}{\tilde{\lambda}_t^P} + \chi_t(1-\rho_B) m p_t^h$
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	$1 + r_t = \max\left[0; (1+r_{t-1})^{\rho_r}\left((1+r)\left(\frac{y_t^{GDP}}{y^{GDP}}\right)^{\phi_Y}\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi}\right)^{1-\rho_r}\right]$
29. Final output	$y_t = \left(\frac{A\xi}{\nu}\right)^{\frac{\xi}{1-\xi}} Z_t^{\frac{1}{1-\xi}} \mu_t^{\frac{\xi}{\xi-1}} \tilde{k}_t^\alpha L_t^{1-\alpha}, \quad \tilde{k}_t = u_t k_t$

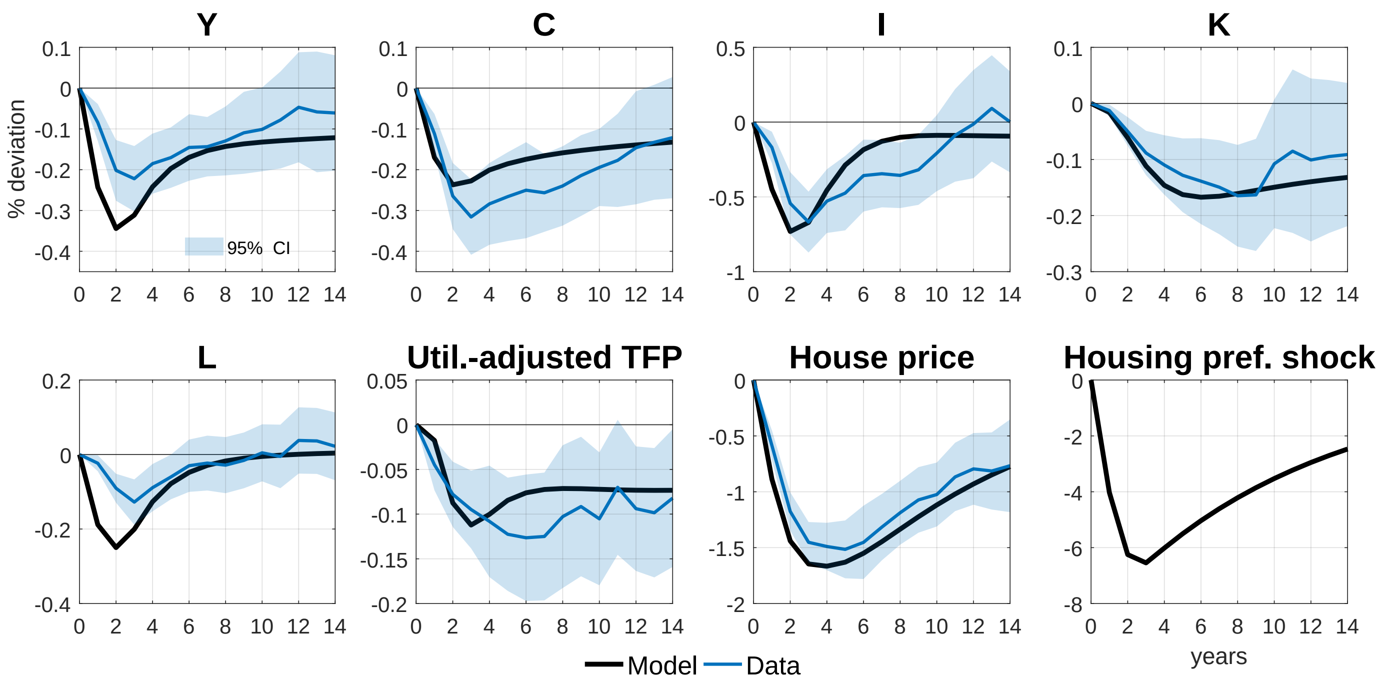
Note: where appropriate, lower-case letters denote stationary counterparts of original variables, i.e. $c_t = \frac{C_t}{N_t}$.

Table 4: Structural parameters [cited on page 21]

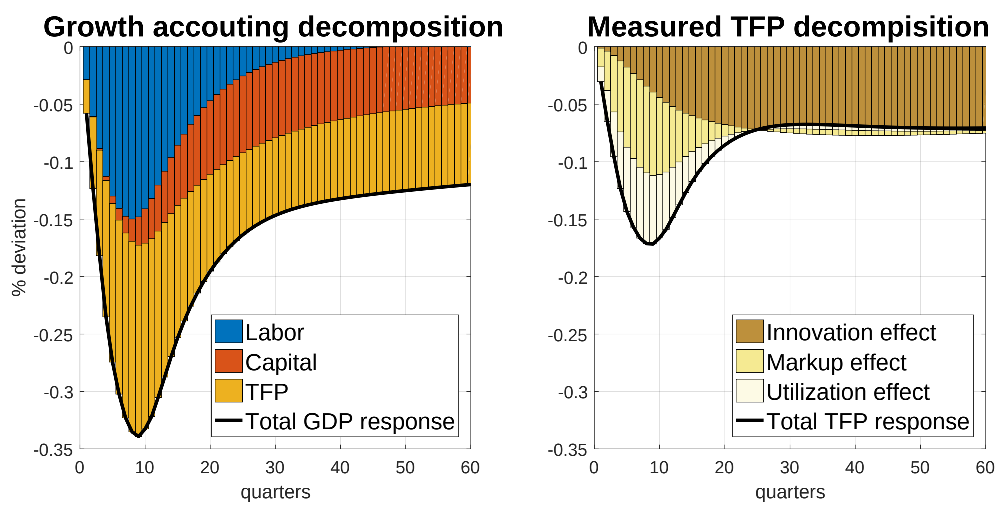
	Calibrated parameters:		Source / target
β_S	Savers discount factor	0.9968	4% annual real interest rate
β_B	Borrowers discount factor	0.9918	
σ	Relative risk aversion	2	Conventional
$1/\epsilon_L$	Frisch elasticity of labor supply	1	Conventional
$-1/\epsilon_h$	Price elasticity of housing demand	-0.2	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
c_1	Price adjustment cost	-0.65	Steady-state utilization $u = 1$
	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 24]

(a) IRF matching



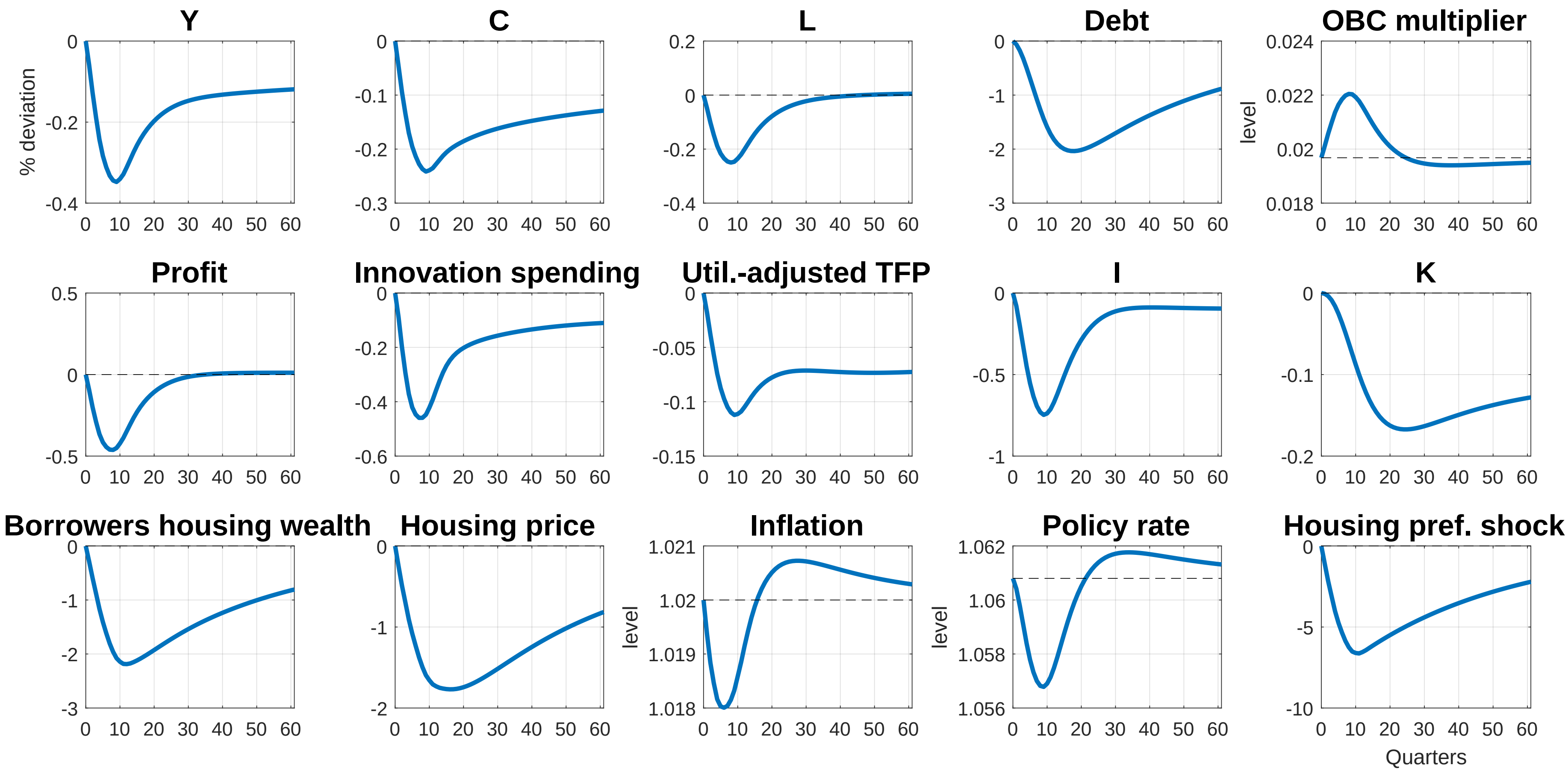
(b) Model-based decompositions



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

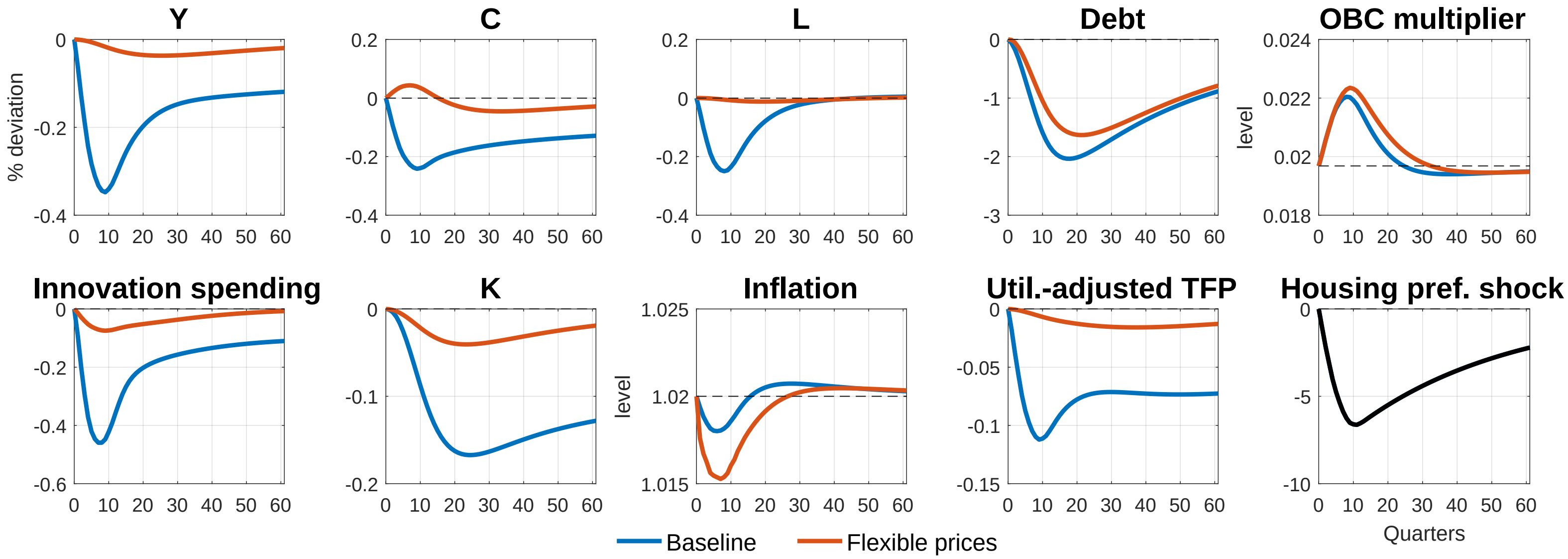
Figure 8: Baseline simulation, extended set of impulse responses [cited on page 25]



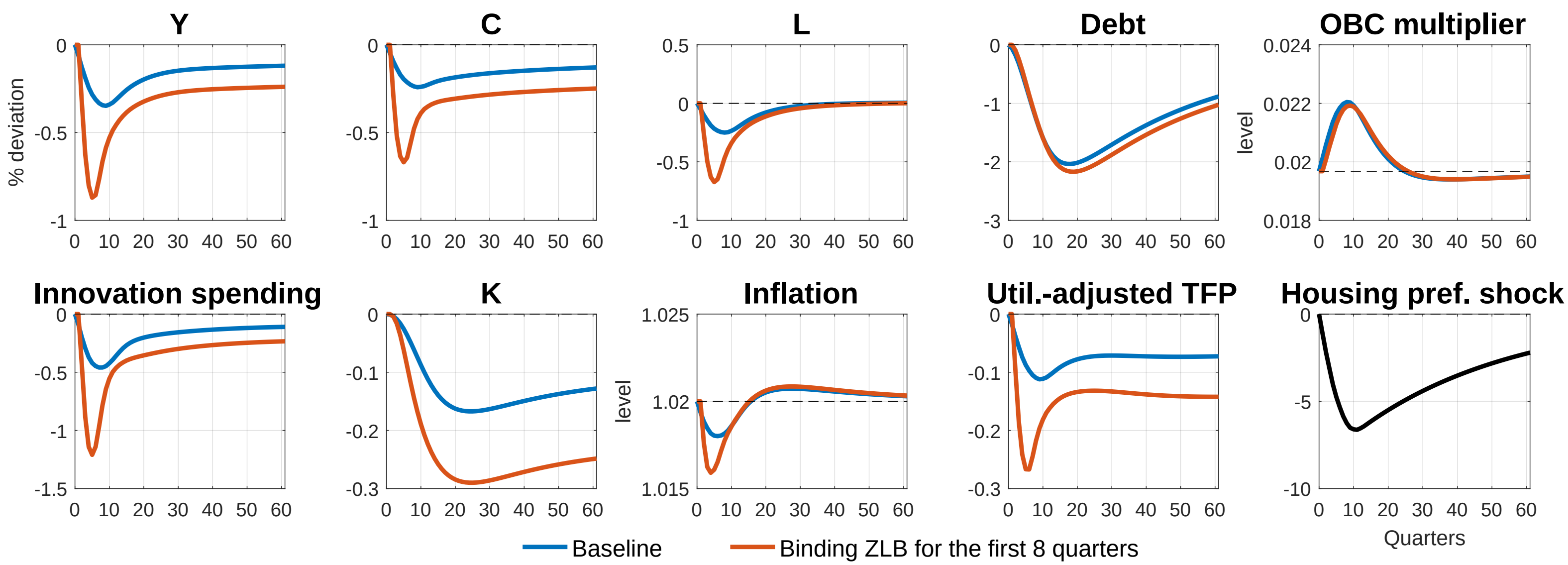
Note: a broader set of impulse responses of the baseline, IRF-matching, simulation, figure 7. Inflation rate and the policy rate are annualized. See details in section 4.1.4.

Figure 9: Baseline simulation, aggregate demand channel [cited on page 26]

(a) The effect of nominal rigidity



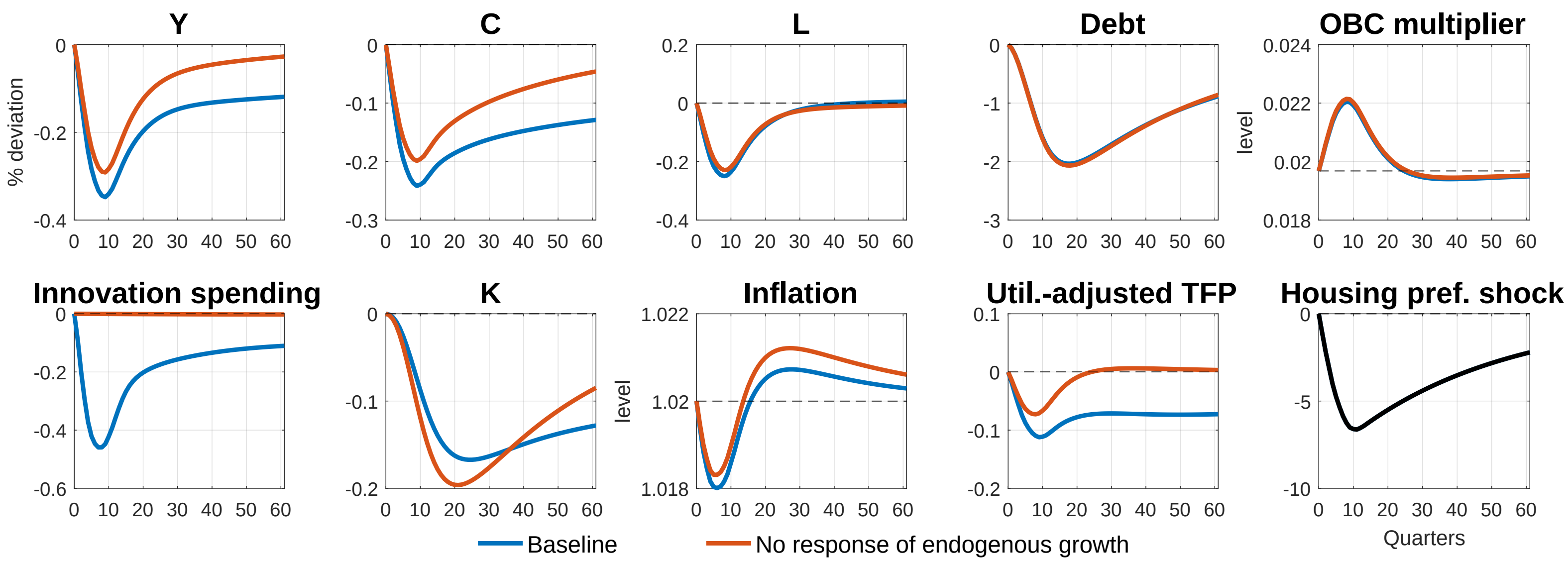
(b) The effect of a binding zero lower bound



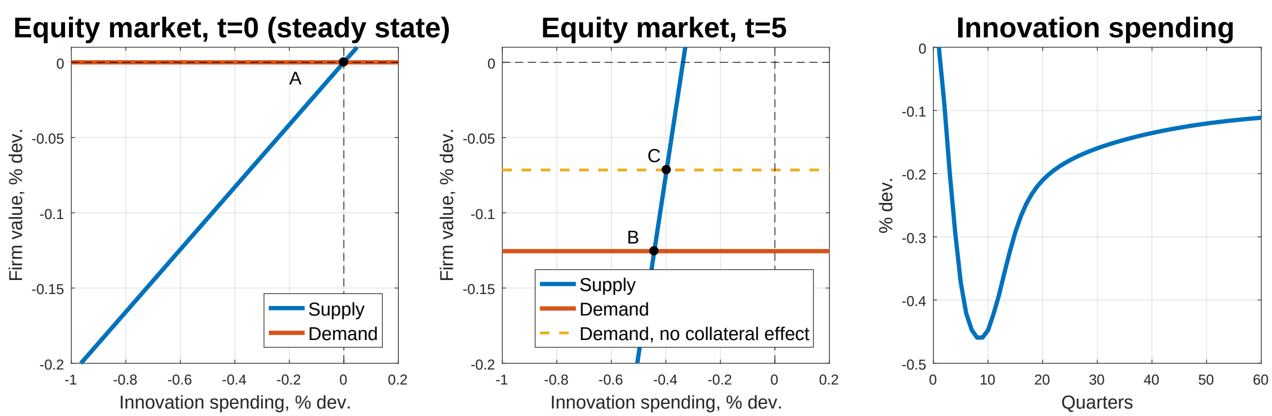
Note: counterfactual responses to the baseline simulation, figure 8. Panel (a): flexible price counterfactual by setting $\psi_p = 0$. Panel (b): net effect of the housing preference shock conditional on a savers discount rate shock that makes the zero lower bound bind for the first 8 quarters. See details in section 4.2.1.

Figure 10: Baseline simulation, endogenous growth channel [cited on page 27]

(a) No endogenous response of productivity growth



(b) Model-consistent intermediate-firm equity market equilibrium



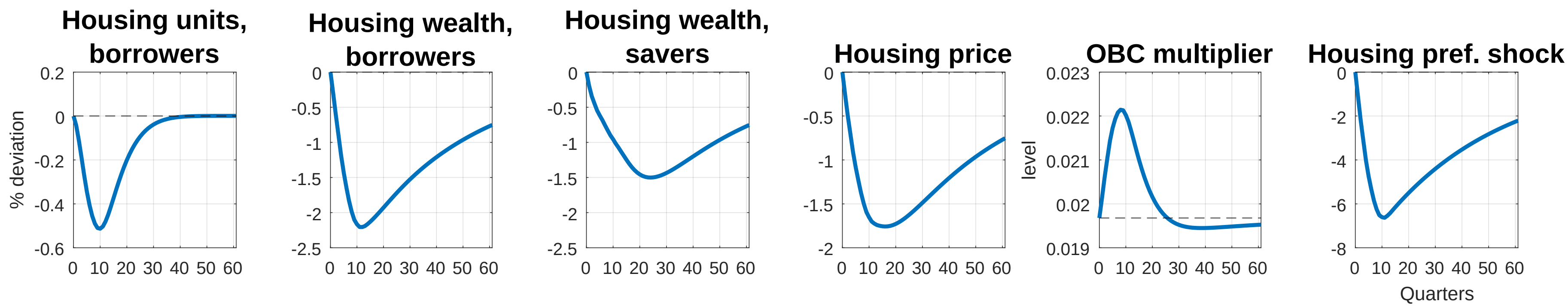
Note: counterfactual responses to the baseline simulation, figure 8. Panel (b) illustrates equity market dynamics (firm value v_t and innovation s_t) using model-implied linear demand and supply curves. See section 4.2.2 and appendix D.3.

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

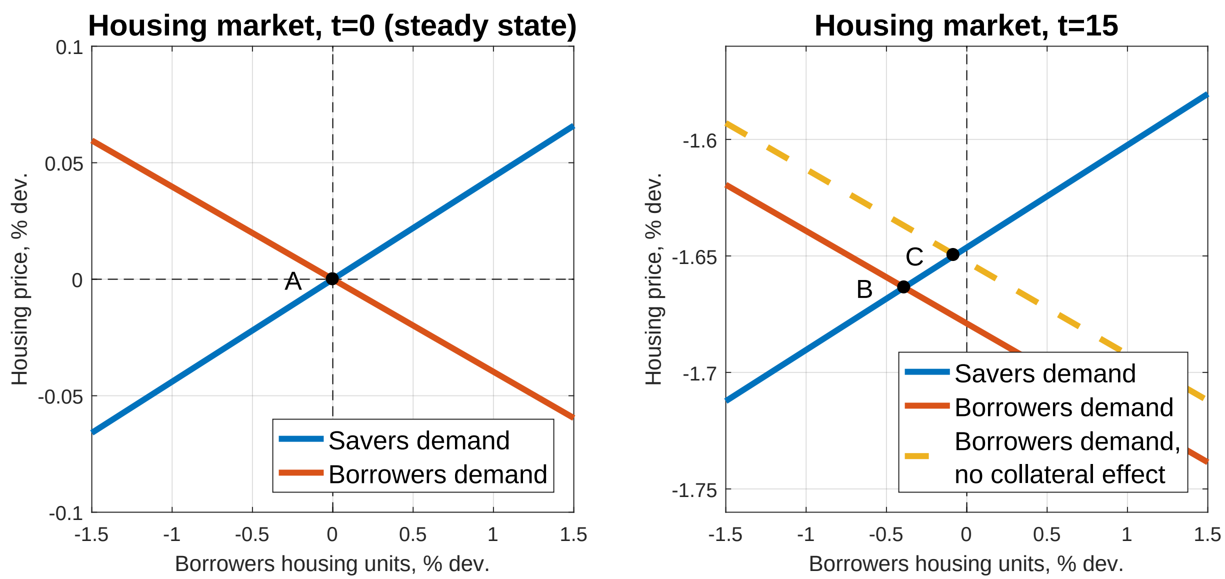
$$\text{Equity supply: } \mathsf{v}_t = A_{v3}\mathsf{s}_t + \underbrace{\Phi_N(\mathsf{S}_{t+1}, \mathsf{S}_t)}_{\text{Adj. cost}}$$

Figure 11: Baseline simulation, Fisherian debt deflation channel [cited on page 29]

(a) Details of the housing market dynamics



(b) Model-consistent housing market equilibrium



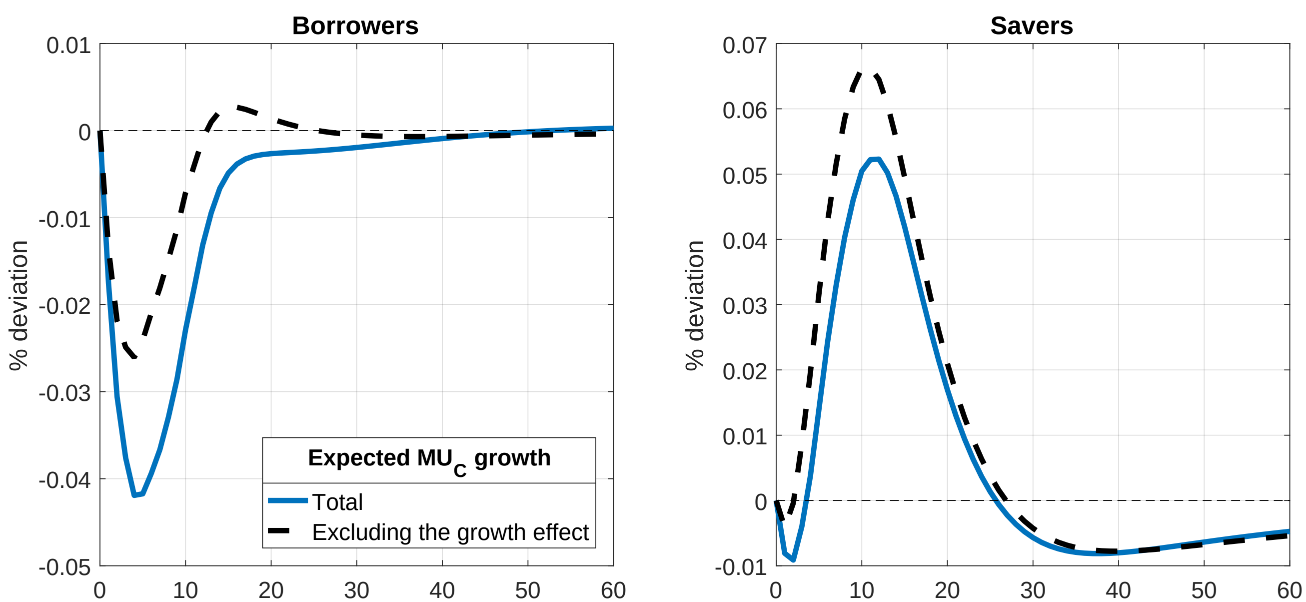
Note: details of the baseline simulation, figure 8. Panel (b) illustrates the housing market dynamics (price $\mathsf{p}^{\mathsf{h}}_{\mathsf{t}}$ and borrowers' housing share $\mathsf{h}^{\mathsf{B}}_{\mathsf{t}}$) using model-implied linear demand curves. See section 4.2.3 and appendix D.2.

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

Borrowers housing demand: $\mathsf{p}^{\mathsf{h}}_{\mathsf{t}} = -A^B_{h1}\mathsf{h}^{\mathsf{B}}_{\mathsf{t}} + \underbrace{A^B_{h2}\vartheta_{\mathsf{t}}}_{\text{Pref. shock}} - \underbrace{A^S_{h2}\tilde{\lambda}^{\mathsf{B}}_{\mathsf{t+1}}}_{\text{Wealth effect}} + \underbrace{A^B_{h3}\,\mathbb{E}_t\left(\mathsf{p}^{\mathsf{h}}_{\mathsf{t+1}} + \mathsf{g}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}}\right)}_{\text{Next-period discounted return}} - \underbrace{A^B_{h4}\chi_{\mathsf{t}} + A^B_{h5}\,\mathbb{E}_t(\chi_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \Pi_{\mathsf{t+1}})}_{\text{Collateral constraint wedge}}$

Figure 12: Baseline simulation, expected income growth channel [cited on page 30]

Expected growth of marginal utility of consumption:



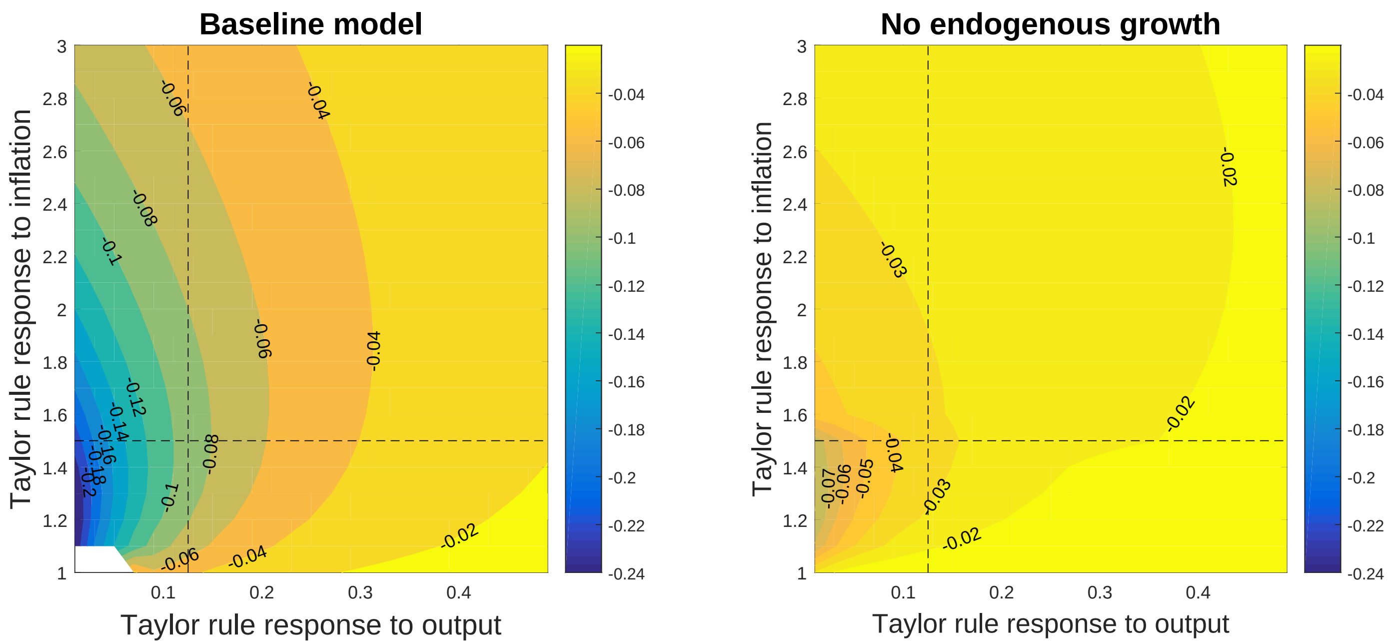
Note: details of the baseline simulation, figure 8. The figure illustrates the direct contribution of expected productivity growth to the growth of marginal utility of consumption based on the linearized optimality conditions. See details in section 4.2.4 and appendix D.4.

$$\text{Savers:} \quad \mathbb{E}_t\, \mathsf{u}'_{c^S_{t+1}} - \mathsf{u}'_{c^S_t} = -\mathbb{E}_t\, \mathsf{R}_{t+1} + \sigma\, \mathbb{E}_t\, \mathsf{g}_{t+1}$$

$$\text{Borrowers:} \quad \mathbb{E}_t\, \mathsf{u}'_{c^B_{t+1}} - \mathsf{u}'_{c^B_t} = \underbrace{-\mathbb{E}_t\, \mathsf{R}_{t+1}}_{\text{Real interest rate}} + \underbrace{\sigma\, \mathbb{E}_t\, \mathsf{g}_{t+1}}_{\text{Productivity growth}} - \underbrace{A^B_{\Lambda 1}\chi_t + A^B_{\Lambda 2}\, \mathbb{E}_t(\chi_{t+1} - \mathsf{R}_{t+1} - \Pi_{t+1})}_{\text{Collateral constraint wedge}}$$

FIGURE 13: BASELINE SIMULATION, WELFARE COST AND MONETARY POLICY [cited on page 30]

Welfare cost under different Taylor rule parameters (% of steady-state consumption)

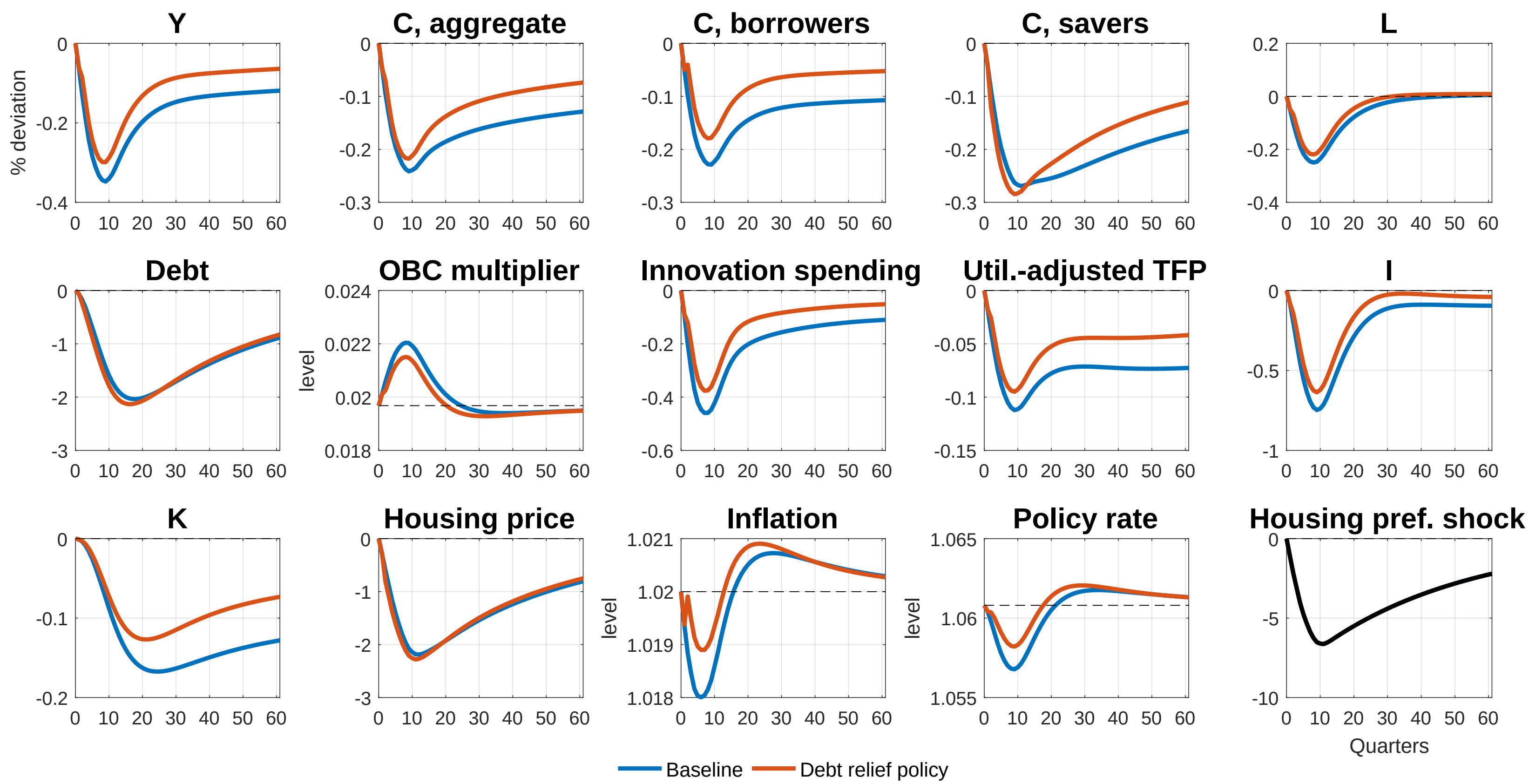


Note: counterfactual scenarios to the baseline simulation, figure 8, under different parameters of the Taylor rule: $1 + r_t = (1 + r_{t-1})^{\rho_r} \left((1 + r)\left(y_t^{GDP}/y^{GDP}\right)^{\phi_Y} (\Pi_t/\Pi)^{\phi_\Pi}\right)^{1-\rho_r}$.

The welfare cost is expressed in steady-state consumption equivalent under different values of Taylor ryle parameters ϕ_Y and ϕ_Π. Dashed lines mark baseline parameter values.

See details in section 5.

Figure 14: Baseline simulation, debt relief policy [cited on page 31]



Note: counterfactual scenario to the baseline in figure 8. Inflation rate and the policy rate are annualized.

Debt relief policy consists of a temporary transfer from savers to borrowers equivalent to a 0.1% of borrowers steady-state debt burden implemented at $t = 2$; the persistence of the transfer is set to 0.9.

See details in section 5.

References

1. Acharya, S., Bengui, J., Dogra, K., and Wee, S. L. (2018). Slow Recoveries and Unemployment Traps: Monetary Policy in a Time of Hysteresis. *CEPR Discussion Paper*.
2. Adjemian, S., Bastani, H., Juillard, M., Karame, F., Maih, J., Mihoubi, F., Perendia, G., Pfeifer, J., Ratto, M., and Villemot, S. (2011). Dynare: Reference Manual, Version 4. Technical report, CEPREMAP.
3. Adjemian, S. and Juillard, M. (2013). Stochastic extended path approach. (2011):1–21.
4. Aghion, P. and Howitt, P. (1992). A Model of Growth Through Creative Destruction. *Econometrica*, 60(2):323.
5. Akinci, Ö. and Chahrour, R. (2018). Good news is bad news: Leverage cycles and sudden stops. *Journal of International Economics*, 114:362–375.
6. Andersen, A. L., Duus, C., and Jensen, T. L. (2014). Household Debt and Consumption During the Financial Crisis: Evidence from Danish Micro Data. *Danmarks Nationalbank Working Papers*.
7. Anzoategui, D., Comin, D., Gertler, M., and Martinez, J. (2019). Endogenous Technology Adoption and R&D as Sources of Business Cycle Persistence. *American Economic Journal: Macroeconomics*, 11(3):67–110.
8. Ates, S. T. and Saffie, F. E. (2020). Fewer but Better: Sudden Stops, Firm Entry, and Financial Selection. *American Economic Journal: Macroeconomics*.
9. Bahadir, B. and Gumus, I. (2016). Credit decomposition and business cycles in emerging market economies. *Journal of International Economics*, 103:250–262.
10. Basu, S., Fernald, J. G., and Kimball, M. S. (2006). Are Technology Improvements Contractionary? *American Economic Review*, 96(5):1418–1448.
11. Benhabib, J., Rogerson, R., and Wright, R. (1991). Homework in Macroeconomics: Household Production and Aggregate Fluctuations. *Journal of Political Economy*, 99(6):1166–1187.
12. Benigno, G., Chen, H., Otrok, C., Rebucci, A., and Young, E. R. (2016). Optimal Capital Controls and Real Exchange Rate Policies: a Pecuniary Externality Perspective. *Journal of Monetary Economics*, 84:147–165.
13. Benigno, G. and Fornaro, L. (2018). Stagnation Traps. *Review of Economic Studies*, 85(3):1425–1470.
14. Benigno, P., Eggertsson, G., and Romei, F. (2020). Dynamic Debt Deleveraging and Optimal Monetary Policy. *American Economic Journal: Macroeconomics*, 12(2):310–50.
15. Benigno, P. and Romei, F. (2014). Debt Deleveraging and the Exchange Rate. *Journal of International Economics*, 93:1–16.
16. Bernard, A. B., Redding, S. J., and Schott, P. K. (2010). Multiple-product firms and product switching. *American Economic Review*, 100(1):70–97.
17. Bianchi, F., Kung, H., and Morales, G. (2019). Growth, Slowdowns, and Recoveries.

Journal of Monetary Economics, 101:47–63.

18. Bianchi, J. and Mendoza, E. G. (2018). Optimal Time-Consistent Macroprudential Policy. *Journal of Political Economy*, 126(2):588–634.

19. Bilbiie, F. O., Ghironi, F., and Melitz, M. J. (2012). Endogenous Entry, Product Variety, and Business Cycles. *Journal of Political Economy*, 120(2):304–345.

20. Blanchard, O., Cerutti, E., and Summers, L. (2015). Inflatoin and Activity - Two Explorations and their Monetary Policy Implications.

21. Blanchard, O. J. and Summers, L. H. (1987). Hysteresis in Unemployment. *European Economic Review*, 31:288–295.

22. Bordo, M. D. and Haubrich, J. G. (2010). Credit crises, money and contractions: An historical view. *Journal of Monetary Economics*, 57(1):1–18.

23. Born, B. and Pfeifer, J. (2016). The New Keynesian Wage Phillips Curve: Calvo vs. Rotemberg. *Dynare Working Papers*.

24. Bunn, P., Rostom, M., and Bank of England (2015). Household Debt and Spending in the United Kingdom. *Bank of England Working Papers*, (554).

25. Burnside, C. and Eichenbaum, M. (1996). American Economic Association Factor-Hoarding and the Propagation of Business-Cycle Shocks. *American Economic Review*, 86(5):1154–1174.

26. Caballero, R. and Jaffe, A. (1993). How High are the Giants' Shoulders: An Empirical Assessment of Knowledge Spillovers and Creative Destruction in a Model of Economic Growth. *NBER Macroeconomics Annual*.

27. Campbell, J. Y. and Mankiw, N. G. (1989). International evidence on the persistence of economic fluctuations. *Journal of Monetary Economics*, 23(2):319–333.

28. Cerra, V. and Saxena, S. C. (2008). Growth Dynamics: The Myth of Economic Recovery. *American Economic Review*, 98(1):439–457.

29. Cerutti, E., Dagher, J., and Dell 'Ariccia, G. (2015). Housing Finance and Real-Estate Booms: A Cross-Country Perspective. *IMF Staff Discussion Note*.

30. Christiano, L., Eichenbaum, M., and Rebelo, S. (2016). When Is the Government Spending Multiplier Large? *Journal of Political Economy*, 119(1):78–121.

31. Christiano, L. J., Eichenbaum, M., and Evans, C. L. (2005). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy*, 113(1):1–45.

32. Comin, D. and Gertler, M. (2006). Medium-term Business Cycles. *American Economic Review*, 96(3):523–551.

33. Comin, D., Loayza, N., Pasha, F., and Serven, L. (2014). Medium Term Business Cycles in Developing Countries. *American Economic Journal: Macroeconomics*, 6(4):209–245.

34. Corradin, S. and Popov, A. (2015). House Prices, Home Equity Borrowing, and Entrepreneurship. *Review of Financial Studies*, 28(8):2399–2428.

35. Correa-López, M. and de Blas, B. (2018). Faraway, So Close! Technology Diffusion and Firm Heterogeneity in the Medium Term Cycle of Advanced Economies. *Banco de*

España working paper no. 1835.

36. Croce, M. M., Nguyen, T. T., and Schmid, L. (2012). The Market Price of Fiscal Uncertainty. *Journal of Monetary Economics*, 59:401–416.

37. Davis, M. A. and Heathcote, J. (2007). The Price and Quantity of Residential Land in the United States. *Journal of Monetary Economics*, 54(8):2595–2620.

38. Davis, S. J. and Haltiwanger, J. C. (2019). Dynamism Diminished: The Role of Housing Markets and Credit Conditions. *NBER Working Paper*.

39. Delong, J. B. and Summers, L. H. (2012). Fiscal Policy in a Depressed Economy. *Brookings Papers on Economic Activity*, 2012(1):233–297.

40. Eggertsson, G. B. (2008). Great Expectations and the End of the Depression. *American Economic Review*, 98(4):1476–1516.

41. Eggertsson, G. B. and Krugman, P. (2012). Debt, Deleveraging, and the Liquidity Trap: A Fisher-Minsky-Koo Approach. *Quarterly Journal of Economics*, 127(3):1469–1513.

42. Eggertsson, G. B., Woodford, M., Friedman, B. M., and Gertler, M. (2003). The Zero Bound on Interest Rates and Optimal Monetary Policy. *Brookings Papers on Economic Activity*, 2003(1):139–233.

43. Fatás, A. (2002). The Effects of Business Cycle on Growth. *Central Bank of Chile Working Papers*.

44. Fatás, A. and Summers, L. H. (2018). The Permanent Effects of Fiscal Consolidations. *Journal of International Economics*, 112:238–250.

45. Feenstra, R. C., Inklaar, R., and Timmer, M. P. (2015). The Next Generation of the Penn World Table. *American Economic Review*, 105(10):3150–3182.

46. Fernald, J. G., Hall, R. E., Stock, J. H., and Watson, M. W. (2017). The Disappointing Recovery of Output after 2009. *Brookings Papers on Economic Activity*, 2017:1–81.

47. Ferrero, A. (2015). House price booms, current account deficits, and low interest rates. *Journal of Money, Credit and Banking*, 47(S1):261–293.

48. Fisher, I. (1933). The Debt-Deflation Theory of Great Depressions. *Econometrica*, 1(4):337.

49. Fisher, J. D. (2015). On the structural interpretation of the Smets-Wouters "Risk Premium" shock. *Journal of Money, Credit and Banking*, 47(2-3):511–516.

50. Galí, J. and Gertler, M. (1999). Inflation Dynamics: A Structural Econometric Analysis. *Journal of Monetary Economics*, 44(2):195–222.

51. Garcia-Macia, D. (2015). The Financing of Ideas and the Great Deviation. *SIEPR Discussion Paper*.

52. Garga, V. and Singh, S. (2020). Output Hysteresis and Optimal Monetary Policy. *Journal of Monetary Economics*.

53. Gertler, M. and Karadi, P. (2011). A Model of Unconventional Monetary Policy. *Journal of Monetary Economics*, 58(1):17–34.

54. Giroud, X. and Mueller, H. M. (2017). Firm leverage, consumer demand, and employ-

ment losses during the great recession. *Quarterly Journal of Economics*, 132(1):271–316.

55. Glick, R. and Lansing, K. J. (2010). Global Household Leverage, House Prices, and Consumption. *FRBSF Economic Letter.*

56. Gordon, R. J. (2015). The Economics of Secure Stagnation: A Supply-Side View. *American Economic Review: Papers & Proceedings*, 105(5):54–59.

57. Gornemann, N. (2015). Sovereign Default, Private Investment, and Economic Growth. *Mimeo.*

58. Gourio, F., Kashyap, A. K., and Sim, J. W. (2018). The Trade offs in Leaning Against the Wind. *IMF Economic Review*, 66(1):70–115.

59. Gourio, F., Messer, T., and Siemer, M. (2016). Firm Entry and Macroeconomic Dynamics: A State-level Analysis. In *American Economic Review: Papers & Proceedings*, volume 106, pages 214–218.

60. Greenwood, J., Hercowitz, Z., and Huffman, G. W. (1988). Investment, Capacity Utilization and the Real Business Cycle. *The American Economic Review*, 78(3):402–417.

61. Grossman, G. M. and Helpman, E. (1991). Quality Ladders in the Theory of Growth. *The Review of Economic Studies*, 58(1):43.

62. Guerrieri, L. and Iacoviello, M. (2015). OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily. *Journal of Monetary Economics*, 70:22–38.

63. Guerrieri, L. and Iacoviello, M. (2017). Collateral Constraints and Macroeconomic Asymmetries. *Journal of Monetary Economics*, 90:28–49.

64. Guerrieri, V. and Lorenzoni, G. (2017). Credit Crises, Precautionary Savings, and the Liquidity Trap. *The Quarterly Journal of Economics*, 132(3):1427–1467.

65. Guerron-Quintana, P. A. and Jinnai, R. (2019). Financial Frictions, Trends, and the Great Recession. *Quantitative Economics*, 10(2):735–773.

66. Guren, A. M., Mckay, A., Nakamura, E., and Steinsson, J. (2018). Housing Wealth Effects: The Long View. *NBER Working Paper 24729.*

67. Hanushek, E. A. and Quigley, J. M. (1980). What is the Price Elasticity of Housing Demand? *The Review of Economics and Statistics*, 62(3):449–454.

68. Holden, T. (2016). Medium Frequency Cycles in a Stationary World.

69. Holden, T. D. (2019). Existence and Uniqueness of Solutions to Dynamic Models with Occasionally Binding Constraints.

70. Iacoviello, M. (2005). House prices, borrowing constraints, and monetary policy in the business cycle. *American Economic Review*, 95(3):739–764.

71. Iacoviello, M. and Minetti, R. (2006). International Business Cycles with Domestic and Foreign Lenders. *Journal of Monetary Economics*, 53(8):2267–2282.

72. Iacoviello, M. and Neri, S. (2010). Housing Market Spillovers: Evidence from an Estimated DSGE Model. *American Economic Journal: Macroeconomics*, 2(2):125–164.

73. Ikeda, D. and Kurozumi, T. (2018). Slow Post-Financial Crisis Recovery and Monetary Policy. *Federal Reserve Bank of Dallas, Globalization Institute Working Papers*,

2018(347).

74. Ilzetzki, E., Reinhart, C. M., and Rogoff, K. S. (2019). Exchange Arrangements Entering the Twenty-First Century: Which Anchor will Hold? *The Quarterly Journal of Economics*, 134(2):599–646.

75. Imbs, J. M. (1999). Technology, Growth and the Business Cycle. *Journal of Monetary Economics*, 44(1):65–80.

76. IMF (2012). World Economic Outlook - Growth Resuming, Dangers Remain. Technical report.

77. Jaimovich, N. and Rebelo, S. (2009). Can News about the Future Drive the Business Cycle? *American Economic Review*, 99(4):1097–1118.

78. Jensen, H., Petrella, I., Ravn, S. H., and Santoro, E. (2019). Leverage and Deepening Business Cycle Skewness. *American Economic Journal: Macroeconomics*.

79. Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *American Economic Review*, 95(1):161–182.

80. Jordà, Ò., Schularick, M., and Taylor, A. M. (2013). When Credit Bites Back. *Journal of Money, Credit and Banking*, 45(2):3–28.

81. Jordà, Ò., Schularick, M., and Taylor, A. M. (2015). Leveraged Bubbles. *Journal of Monetary Economics*, 76:S1–S20.

82. Jorda, O., Schularick, M., and Taylor, A. M. (2016). Macrofinancial History and the New Business Cycle Facts. *Federal Reserve Bank of San Francisco, Working Paper Series*, 31(1):01–57.

83. Justiniano, A., Primiceri, G. E., and Tambalotti, A. (2015). Household leveraging and deleveraging. *Review of Economic Dynamics*, 18(1):3–20.

84. Kaplan, G., Mitman, K., and Violante, G. L. (2016). Non-Durable Consumption and Housing Net Worth in the Great Recession: Evidence from Easily Accessible Data. *NBER Working Paper*.

85. Kaplan, G., Mitman, K., and Violante, G. L. (2020). The Housing Boom and Bust: Model Meets Evidence. *Journal of Political Economy*, 128(9):3285–3345.

86. King, R. G. and Rebelo, S. T. (1999). Resuscitating Real Business Cycles. *Handbook of Macroeconomics*, 1:927–1007.

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

88. Knowles, M. (2018). Capital Deaccumulation and the Large Persistent Effects of Financial Crises.

89. Korinek, A. (2018). Regulating capital flows to emerging markets: An externality view. *Journal of International Economics*, 111:61–80.

90. Korinek, A. and Simsek, A. (2016). Liquidity Trap and Excessive Leverage. *American Economic Review*, 106(3):699–738.

91. Kozlowski, J., Veldkamp, L., and Venkateswaran, V. (2019). The Tail that Wags the Economy: Belief-Driven Business Cycles and Persistent Stagnation. *NBER Working*

Paper.

92. Krishnamurthy, A. and Muir, T. (2017). How Credit Cycles across a Financial Crisis. *NBER Working Paper*.

93. Kydland, F. E., Rupert, P., and Šustek, R. (2016). Housing Dynamics over the Business Cycle. *International Economic Review*, 57(4):1149–1177.

94. Laeven, L. and Valencia, F. (2013). Systemic Banking Crises Database. *IMF Economic Review*, 61(2):225–270.

95. Levchenko, A. A. and Pandalai-Nayar, N. (2018). TFP, News, and Sentiments: the International Transmission of Business Cycles. *Journal of the European Economic Association*.

96. Liu, Z., Miao, J., and Zha, T. (2016). Land Prices and Unemployment. *Journal of Monetary Economics*, 80:86–105.

97. Liu, Z., Wang, P., and Zha, T. (2013). Land-Price Dynamics and Macroeconomic Fluctuations. *Econometrica*, 81(3):1147–1184.

98. Lo, S. and Rogoff, K. (2015). Secular Stagnation, Debt Overhang and Other Rationales for Sluggish Growth, Six Years On. *BIS Working Papers*, (482):39.

99. Lombardi, M. J., Mohanty, M., and Shim, I. (2017). The Real Effects of Household Debt in the Short and Long run. *BIS Working Papers*, 607(607):Bank for International Settlements.

100. Mbaye, S., Moreno Badia, M., and Chae, K. (2018). Global Debt Database: Methodology and Sources. *IMF Working Paper*.

101. Mendoza, E. G. (2010). Sudden Stops, Financial Crises, and Leverage. *American Economic Review*, 100(5):1941–1966.

102. Mian, A., Rao, K., and Sufi, A. (2013). Household Balance Sheets, Consumption, and the Economic Slump. *Quarterly Journal of Economics*, 128(4):1687–1726.

103. Mian, A. and Sufi, A. (2014). What Explains the 2007-2009 Drop in Employment? *Econometrica*, 82(6):2197–2223.

104. Mian, A., Sufi, A., and Verner, E. (2017). Household Debt and Business Cycles Worldwide. *Quarterly Journal of Economics*, 132(4):1755–1817.

105. Midrigan, V. and Philippon, T. (2018). Household Leverage and the Recession. *NBER Working Paper*.

106. Moran, P. and Queralto, A. (2018). Innovation, Productivity, and Monetary Policy. *Journal of Monetary Economics*, 93:24–41.

107. Nelson, C. R. and Plosser, C. I. (1982). Trends and Random Walks in Macroeconomic Time Series. *Journal of Monetary Economics*, 10.

108. Piketty, T. and Zucman, G. (2014). Capital is back: wealth-income ratios in rich countries 1700-2010. *Quarterly Journal of Economics*, pages 1255–1310.

109. Queralto, A. (2019). A Model of Slow Recoveries from Financial Crises. *Journal of Monetary Economics*.

110. Ramey, G. and Ramey, V. A. (1995). Cross-Country Evidence on the Link Between Volatility and Growth. *American Economic Review*, 85(5):1138–51.

111. Reinhart, C. M. and Rogoff, K. S. (2009). The Aftermath of Financial Crises. In *American Economic Review: Papers & Proceedings*, volume 99, pages 466–472.

112. Romer, C. D. and Romer, D. H. (2017). New Evidence on the Aftermath of Financial Crises in Advanced Countries. *American Economic Review*, 107(10):3072–3118.

113. Romer, P. M. (1990). Endogenous Technological Change. *Journal of Political Economy*, pages 71–102.

114. Rotemberg, J. J. (1982). Monopolistic Price Adjustment and Aggregate Output. *The Review of Economic Studies*, 49(4):517.

115. Saiz, A. (2010). The Geographic Determinants of Housing Supply. *Quarterly Journal of Economics*, 125(3):1253–1296.

116. Schmalz, M. C., Sraer, D. A., and Thesmar, D. (2017). Housing Collateral and Entrepreneurship. *Journal of Finance*, 72(1):99–132.

117. Schmitz, T. (2017). Endogenous Growth, Firm Heterogeneity and the Long-run Impact of Financial Crises. Technical report.

118. Taylor, A. M., Singh, S. R., and Jord‘a, O. (2020). The Long-run Effects of Monetary Policy. *NBER Working Paper.*

119. Warnock, V. C. and Warnock, F. E. (2008). Markets and Housing Finance. *Journal of Housing Economics*, 17(3):239–251.

120. Woodford, M. (2003). *Interest and Prices: Foundations of a Theory of Monetary Policy.* Princeton University Press.

Housing market cycles, productivity growth, and household debt

Online appendix

Dmitry Brizhatyuk*

Abstract

This not for publication appendix gathers supplementary materials to the paper

*Moody's Analytics, One Canada Square, Canary Wharf, London E14 5AB, UK. dmitry.brizhatyuk@gmail.com, http://dbrizhatyuk.github.io

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

		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

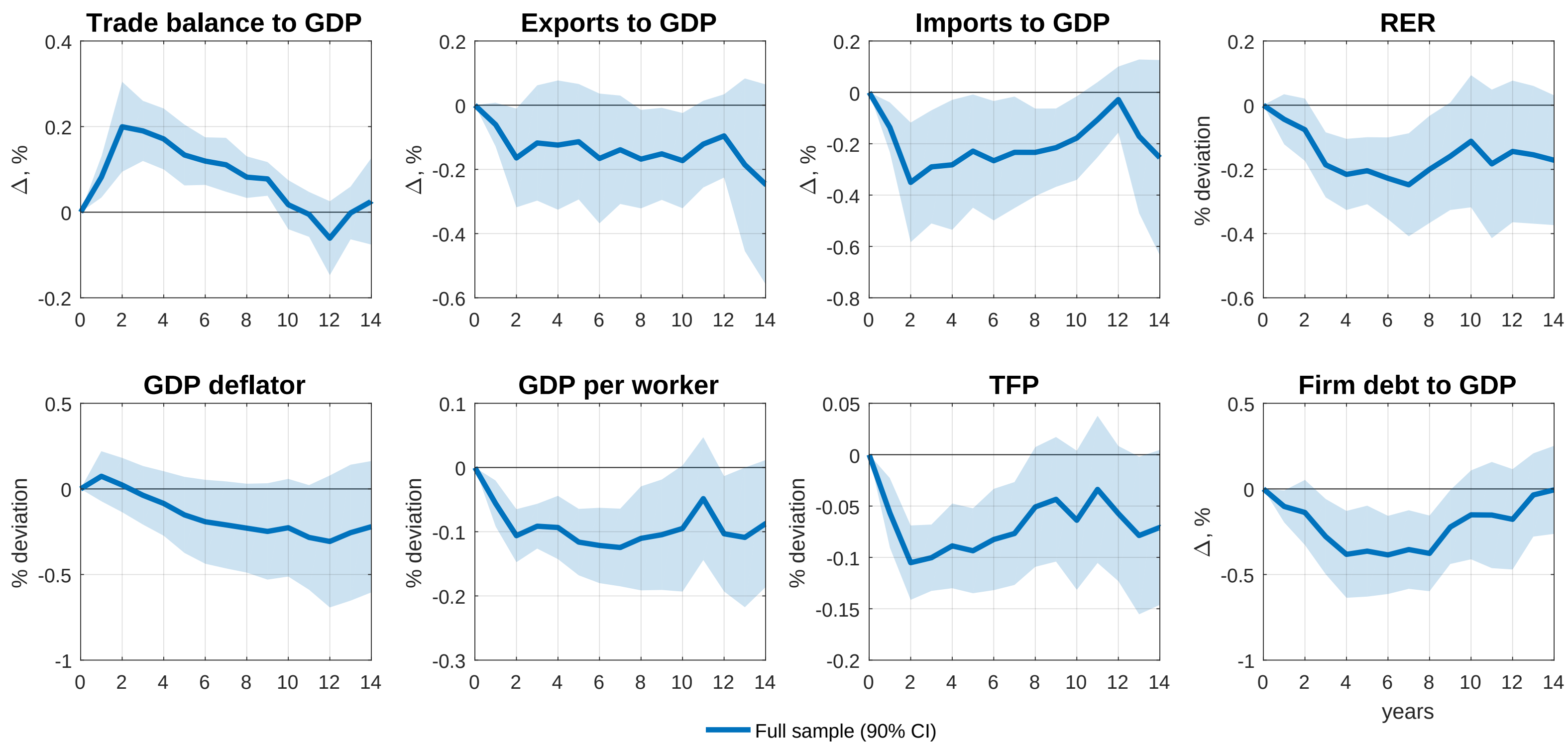
Note: definition similar to Jordà et al. (2015). Blue shaded areas correspond to a 1 st. dev. bound aroung the one-cided HP trend (smoothing parameter = $400000/4^4$).

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

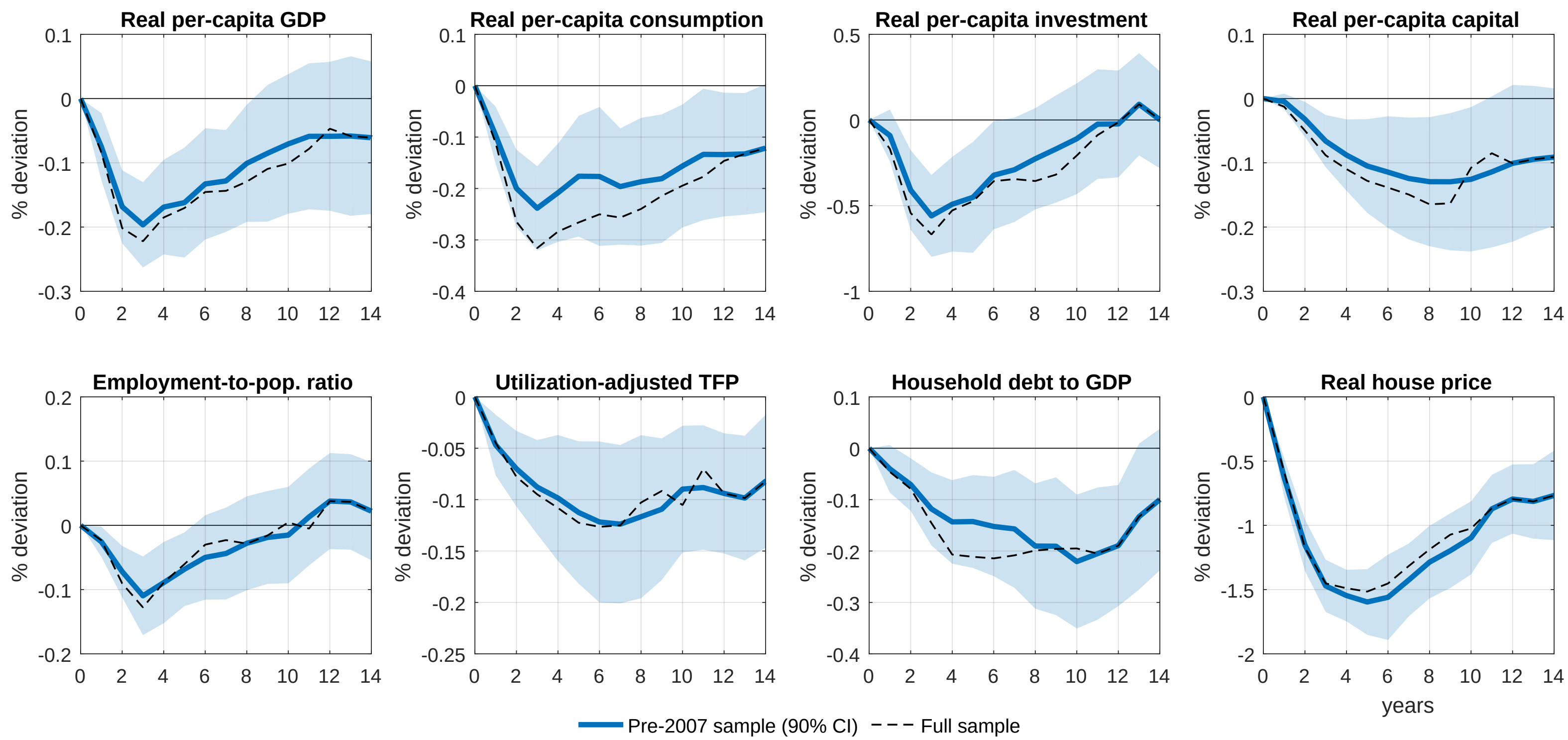
B.1 Cross-country panel

Figure 16: Event study, comovements during housing market crashes, additional results



Note: cross-country panel, local projections: $\Delta_h y_{i,t+h} = \alpha_i^h + \alpha_t^h + \beta^h \Delta p_{i,t}^{\text{crash}} + X_{i,t}\Gamma + \varepsilon_{it}^h$, where $\Delta_h y_{i,t+h}$ is a cumulative $h-$period growth of the variable of interest; $\Delta p_{i,t}^{\text{crash}}$ is the measure of the severity of the housing market crash that starts at period t; α_i^h and α_t^h are country and year fixed effects, respectively; and $X_{i,t}$ and set of macro controls. Standard errors are clustered at the country level. See details in section 2.2

Figure 17: Event study, comovements during housing market crashes, pre-2007 sample

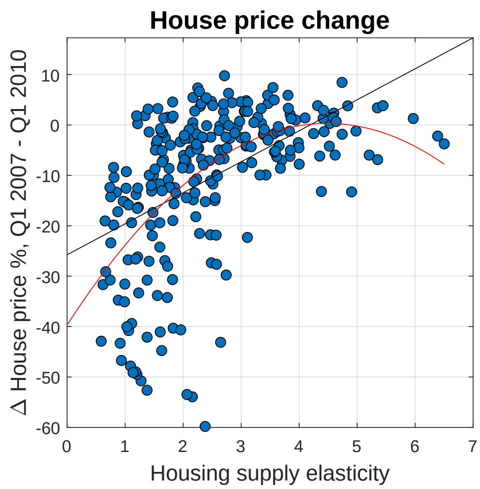


Note: cross-country panel, local projections: $\Delta_h y_{i,t+h} = \alpha_i^h + \alpha_t^h + \beta^h \Delta p_{i,t}^{\text{crash}} + X_{i,t}\Gamma + \varepsilon_{it}^h$, where $\Delta_h y_{i,t+h}$ is a cumulative $h-$period growth of the variable of interest; $\Delta p_{i,t}^{\text{crash}}$ is the measure of the severity of the housing market crash that starts at period t; α_i^h and α_t^h are country and year fixed effects, respectively; and $X_{i,t}$ and set of macro controls. Standard errors are clustered at the country level. See details in section 2.2

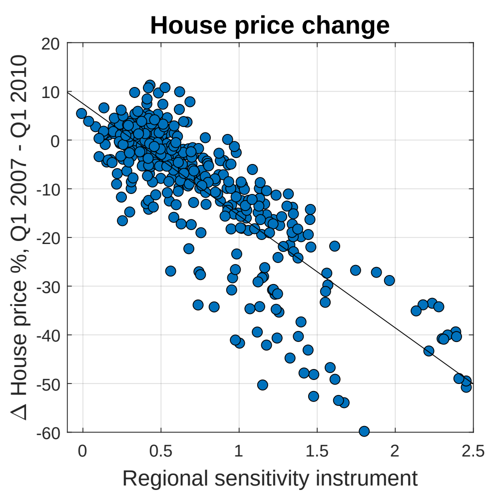
B.2 US MSA-level evidence

FIGURE 18: US MSA-LEVEL EVIDENCE, FIRST STAGE REGRESSIONS

(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 prices are FHFA all-transactions house price indexes.

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 19: House price boom and labor productivity growth

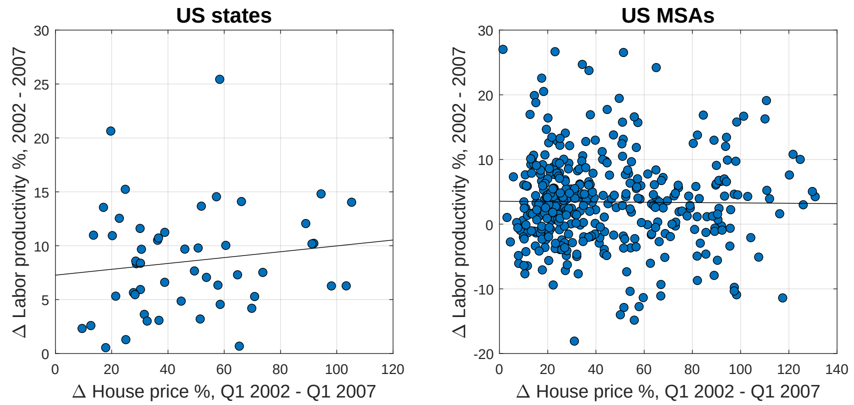


Table 7: Elasticity of labor productivity growth to house price growth

	(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, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

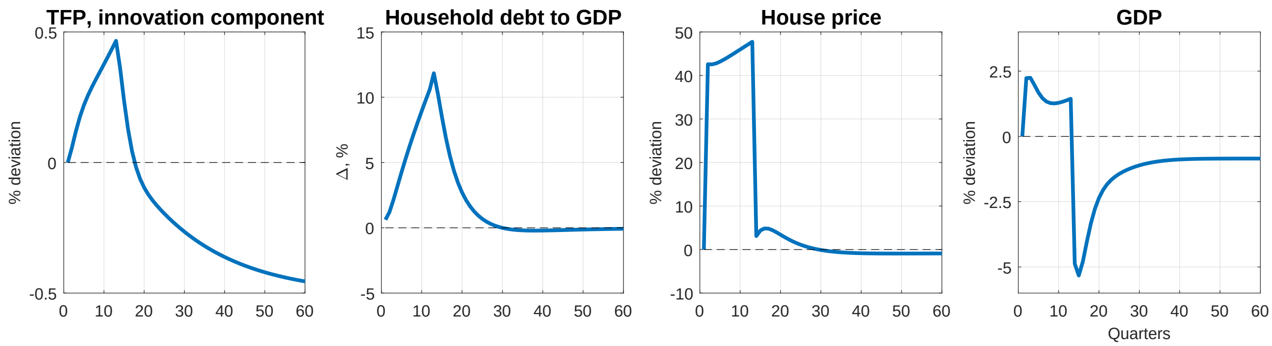
Note: labor productivity is defined as real GDP per worker. State and MSA output and employment data is from BEA. House price growth is based on FHFA all-transactions house price indexes. Controls: 2006 shares in GDP of (a) mining, quarrying, and oil and gas extraction; (b) construction; (c) manufacturing;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

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

C.1 Belief-driven boom and bust cycle

FIGURE 20: RESPONSES TO AN UNREALIZED POSITIVE HOUSING DEMAND NEWS SHOCK



I show that shifts in beliefs about future housing demand can generate the comovement between the house price, household debt, and TFP growth in the model consistent with the panel VAR evidence of section 2.1. The basic idea is that a house price boom can be generated by expectations of higher housing demand in the future, which leads to a crash when these expectations are not met.

In practice, such belief-driven boom-and-bust dynamics can be modeled using an unrealized news shock. Let the housing preference parameter ϑ_t be governed by the AR(1) process, as before. An unrealized news shock can be introduced as follows:

$$\ln(\vartheta_t) = (1-\rho_\vartheta)\ln(\vartheta) + \rho_\vartheta \ln(\vartheta_{t-1}) + \varepsilon^{\vartheta}_{\text{surprise},t} + \varepsilon^{\vartheta}_{\text{news},t-h} \tag{C.1}$$

where $\varepsilon^{\vartheta}_{\text{surprise},t}$ is a standard unanticipated shock, and $\varepsilon^{\vartheta}_{\text{news},t-h}$ is a news shock about housing demand revealed h periods in advance. Setting $\varepsilon^{\vartheta}_{\text{surprise},t} = -\varepsilon^{\vartheta}_{\text{news},t-h}$ means that the news shock is unrealized, i.e. in periods up to $h-1$ agents make decisions anticipating the shift in housing demand, which ceases to happen at $t = h$.

Figure 20 shows the dynamics generated by an unrealized positive housing demand shock. I set the size of the shock such that it generates around a 45% increase in the house price. I set the horizon to $h = 12$, implying the three year duration of the boom phase of the cycle. Initially, expectations of higher housing demand in the future cause the house price to jump. To the extent the house price boom relaxes borrowing constraints of households, it generates a demand-driven expansion.

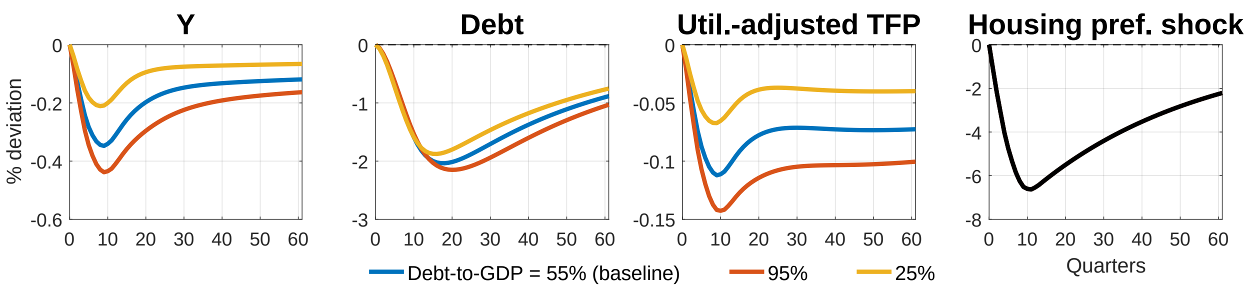
When the expected shock to housing demand ceases to happen, the cycle reverses: the house price falls back towards its long-run level, and so does the household debt with some delay. Importantly, this boom-and-bust cycle generates an asymmetric effect on the economic activity, consistent with the empirical evidence. The housing-boom-led expansion is followed by a deeper contraction, slow recovery, and a persistent loss in productive capacity. This asymmetry is driven by two factors: (1) borrower's collateral constraint becomes slack during the expansion phase and so does not play as much of amplification role as during the downturn;

(2) the house price crash happens at a higher household debt-to-GDP level, which in itself is an important determinant of the magnitude of amplification generated by the collateral constraint, as illustrated below.

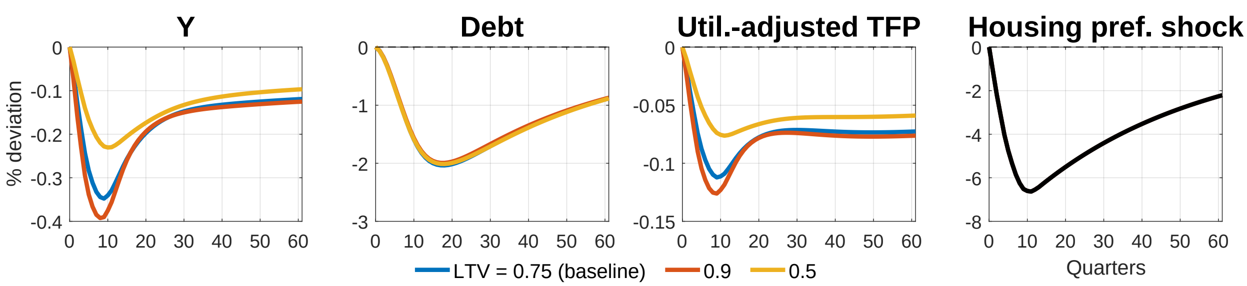
C.2 The amplification role of household debt

Figure 21: Baseline simulation and household debt counterfactuals

(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 8. 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:

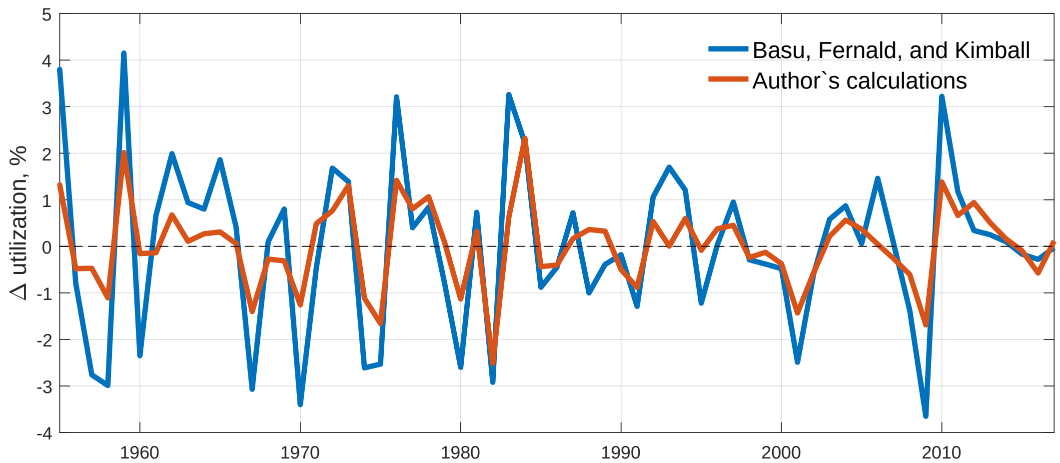
$$u_t = \left(\frac{Y_t / K_t}{Y/K} \right)^{\frac{\delta}{r+\delta}} \tag{D.4}$$

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 labor effort is then the following:

Figure 22: 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

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

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 22 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. $\mathsf{x}_t = \frac{x_t - x}{x}$):

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

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:

$$\mathbb{E}_t \, \Lambda^{\mathsf{S}}_{\mathsf{t,t+1}} = -\,\mathbb{E}_t \, \mathsf{R}_{\mathsf{t+1}}$$
$$\mathbb{E}_t \, \Lambda^{\mathsf{B}}_{\mathsf{t,t+1}} = -\,\mathbb{E}_t \, \mathsf{R}_{\mathsf{t+1}} - \underbrace{A^B_{\Lambda 1}\chi_{\mathsf{t}} + A^B_{\Lambda 2}\,\mathbb{E}_t(\chi_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \Pi_{\mathsf{t+1}})}_{\text{Collateral constraint wedge}}$$

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. Following this result, the final expressions for savers' and borrowers' linearized housing demands are:

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

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

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), as well as the definition of the time-varying innovators productivity ϕ_t:

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

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 versions of equity demand and equity supply are respectively:

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

$$\mathsf{v_t} = A_{v3}\mathsf{s_t} + \underbrace{\phi_N\left(A_{v4}(\mathsf{s_t} + \mathsf{g_{t-1}} - \mathsf{s_{t-1}}) - A_{v5}\,\mathbb{E}_t(\mathsf{s_{t+1}} + \mathsf{g_t} - \mathsf{s_t})\right)}_{\text{R\&D adjustment cost effect}} \tag{D.10}$$

where $A_{v1} = \frac{d}{v+d}$, $A_{v2} = \frac{v}{v+d}$, $A_{v3} = \frac{1-\rho}{\phi v s^{\rho-1}}$, $A_{v4} = \frac{1}{\phi v s^{\rho-1}}$, $A_{v5} = \frac{\beta_B}{\phi v s^{\rho-1} g^{\sigma}}$; and $A^B_{\Lambda 1} = \frac{\chi}{1-\chi}$, $A^B_{\Lambda 2} = \left(\frac{R\Pi}{\rho_B \chi} - 1\right)^{-1}$ are positive constants

D.4 Marginal utility of consumption growth

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 $\mathbb{E}_t \mathsf{\Lambda}^{\mathsf{H}}_{\mathsf{t,t+1}} = \mathbb{E}_t \mathsf{u}'_{\mathsf{c}^{\mathsf{H}}_{\mathsf{t+1}}} - \mathsf{u}'_{\mathsf{c}^{\mathsf{H}}_{\mathsf{t}}} - \sigma\,\mathbb{E}_t \mathsf{g}_{\mathsf{t+1}}$, $H \in \{S, B\}$

$$\mathbb{E}_t \mathsf{u}'_{\mathsf{c}^{\mathsf{S}}_{\mathsf{t+1}}} - \mathsf{u}'_{\mathsf{c}^{\mathsf{S}}_{\mathsf{t}}} = -\mathbb{E}_t \mathsf{R}_{\mathsf{t+1}} + \sigma\,\mathbb{E}_t \mathsf{g}_{\mathsf{t+1}} \tag{D.11}$$

$$\mathbb{E}_t \mathsf{u}'_{\mathsf{c}^{\mathsf{B}}_{\mathsf{t+1}}} - \mathsf{u}'_{\mathsf{c}^{\mathsf{B}}_{\mathsf{t}}} = \underbrace{-\mathbb{E}_t \mathsf{R}_{\mathsf{t+1}}}_{\text{Real interest rate}} + \underbrace{\sigma\,\mathbb{E}_t \mathsf{g}_{\mathsf{t+1}}}_{\text{Productivity growth}} - \underbrace{A^B_{\Lambda 1}\mathsf{\chi}_{\mathsf{t}} + A^B_{\Lambda 2}\,\mathbb{E}_t(\mathsf{\chi}_{\mathsf{t+1}} - \mathsf{R}_{\mathsf{t+1}} - \mathsf{\Pi}_{\mathsf{t+1}})}_{\text{Collateral constraint wedge}} \tag{D.12}$$

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.

D.5 Welfare cost calculation

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

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

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

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

Period utilities can be rewritten in terms of stationary variables and the stock of knowledge N_t as follows: $U(c^H_t, L^H_t) = N_t^{1-\sigma}\left(\left(c^H_t - \upsilon_t \frac{(L^H_t)^{1+\epsilon_L}}{1+\epsilon_L}\right)^{1-\sigma} - 1\right) / (1-\sigma)$ and $G(h^H_t) =$

$N_t^{1-\sigma}\kappa\vartheta_t\frac{(h_t^H)^{1-\epsilon_h}-1}{1-\epsilon_h}$. 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.