

# Can the Productivity Slowdown in Construction Explain US House Prices?

Alessandro Galesi\*

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## Abstract

I consider an open economy with collateralized debt and two sectors, construction and non-construction, whose productivities grow at different rates. I show that when productivity in construction falls, house prices increase. The effect is amplified when the rate at which the economy can borrow is low. As house prices increase, the collateral constraint gets relaxed. If the borrowing rate is sufficiently low, households find optimal to accumulate foreign debt and these capital inflows lead to surges in both residential investment and land prices. In this way house prices rise even further. I calibrate the economy to match the US evidence, which is characterized by a pronounced slowdown in construction productivity and a low borrowing rate. While the productivity slowdown in construction alone can account for the long-run trend in house prices over the 1970's - 2000's, its combination with the low interest rate is crucial to generate the increases in prices of land and housing of the early 2000's. This interaction also accounts for key stylized facts of the US housing cycle: (i) the positive correlation between housing prices and residential investment; (ii) land prices are twice as volatile as house prices; (iii) part of the worsening of the current account. In a closed economy the productivity slowdown in construction cannot account for these facts, hence I conclude that its interaction with the low interest rate is what helps to explain US house prices. Using a Panel VAR with sign restrictions I also show that this mechanism can be important to explain the dynamics of house prices across OECD countries.

*JEL Codes:* D24, L74, O18, O41

*Keywords:* US house prices, construction, productivity slowdown, Baumol cost disease.

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# 1 Introduction

House prices in the United States have been trending since the early 1970's and boomed over the period in between the mid-1990's and early 2000's.<sup>1</sup> What explains the recent evolution of US house prices? The conventional wisdom associates the extraordinarily low borrowing rates observed since the 1990's to the subsequent housing boom that preceded the Great Recession. According to Bernanke (2005), low borrowing rates coupled with massive capital inflows were driven by a *global savings glut*: an increased demand for saving in the rest of the world. Such low rates boosted consumption, residential investment, and eventually house prices. Following this explanation, the recent technological evolutions in the US have had no effect on house prices.

Using US data I document a downward trend in construction productivity relative to other industries which started around the end of the 1960's and still persists. First, I show that this productivity slowdown captures the *long-term trend* in house prices over the 1970's-2000's. Since productivity in construction grows at a lower rate than in other sectors, over time producing houses becomes relatively less efficient and competition in factors of production makes house prices grow faster than prices in the rest of the economy.<sup>2</sup> Second, I show that the combination of the productivity slowdown and the low borrowing interest rate experienced over the recent decades is crucial to account for the *short-term fluctuations* in the housing cycle and the current account. In particular, this interaction accounts for a substantial part of the surges in house prices, land prices, and residential investment of the early 2000's, as well as for part of the concurring worsening of the current account. The idea is that the productivity slowdown in construction that increases house prices also relaxes the collateral constraint. If the borrowing interest rate is sufficiently low, households accumulate foreign debt, and these capital inflows lead to surges in residential investment, land prices, and house prices.

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<sup>1</sup>Himmelberg, Mayer, and Sinai (2005), McCarthy and Peach (2005) and Van Nieuwerburgh and Weill (2010) among others document the historical evolution of US house prices.

<sup>2</sup>This mechanism gets particularly reinforced by the dramatic productivity gains experienced in those sectors which benefited from the adoption of information and communication technologies. For instance, Jorgenson (2001) among others documents that the deployment of semiconductors has led to persistent falls in production costs and prices in manufacturing industries such as aircraft and automobile makers.

I set up an open economy, multi-sector, general equilibrium model to illustrate why the productivity slowdown in construction, and its interaction with the low borrowing rate, can affect house prices. There are two sectors in the economy, construction and non-construction. I extend Ngai and Pissarides (2007) by considering sectoral productivities that grow at different *stochastic* rates due to the presence of sector-specific technology shocks. The non-construction sector produces a nondurable good which is used for either consumption or nonresidential investment. This good can be internationally traded. As in Davis and Heathcote (2005), the construction sector produces structures, which are nontradable, durable, and are used in combination with newly available land to produce houses. This environment implies that in equilibrium, changes in the price of houses are weighed averages of changes in the prices of structures and land. Households can borrow from the rest of the world in an international financial market using their houses as collateral, as in Garriga, Manuelli, and Peralta-Alva (2012). Importantly, I capture as a reduced form the global savings glut by assuming that the interest rate is so low that households find optimal to borrow up to the limit of their collateral constraint.

In this environment, the productivity slowdown affects both the long-term trend and the cyclical fluctuations of house prices. The secular decline in the construction productivity drives the long-term trajectory of house prices, while the transitory shocks account for the deviations from trend. I quantify the role of the construction productivity slowdown by feeding the model with estimated series of sectoral productivities. My main result is twofold. First, the productivity slowdown in construction alone can account for the long-run trend in house prices over the 1970's - 2000's, but understates the increases in prices of houses and land of the early 2000's. Second, the interaction of the productivity slowdown in construction and the low borrowing interest rate is crucial to predict substantial fractions of the increases in prices of houses and land of the early 2000's, and accounts for a number of key stylized facts of the US housing cycle: *(i)* the positive correlation between housing prices and residential investment; *(ii)* land prices are twice as volatile as house prices; *(iii)* part of the worsening of the current account. To understand the relevance of this interaction, I show that a closed economy version of the model predicts a *counterfactual* negative correlation between house prices and residential investment, and

generates prices of houses, land and structures which are roughly equally volatile.

Using a novel industry-level EU KLEMS dataset which spans the period 1947-2010 I robustly document the onset of the US productivity slowdown in construction which is dated around the end of the 1960's and I show that it is still ongoing nowadays.<sup>3</sup> Why did the productivity slowdown in construction occur? Although I do not provide an answer to this question, there is a large civil engineering literature addressing this phenomenon. For example, Allen (1985) argues that the decline in construction productivity is due to shifts in the mix of construction output from large-scale commercial and industrial projects to residential single-family construction projects which are relatively less intensive in skilled labor.<sup>4</sup> Moreover, I exploit the panel variation across US States over the period 2000-2011 to document that relative productivity in construction significantly predicts real house prices even after controlling for key factors such as the price of residential land or the financial conditions of the households.

A productivity slowdown in construction coupled with rising house prices is reminiscent of a *Baumol cost disease*: stagnant sectors, in the sense that their productivity grows at a lower rate than the rest of the economy, will experience increases in costs, and thus in prices, above the average of the economy. William Baumol and his coauthors argue that such disease applies particularly to those activities which are by their nature labor-intensive and feature genuine limitations to productivity enhancements. This paper emphasizes a Baumol cost disease in the US construction, which is effectively a labor-intensive sector: over the 1970's-2010's, about 90 percent of its value added goes to labor compensation, while the same figure for the rest of the economy is nearly 70 percent.<sup>5</sup>

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<sup>3</sup>The dataset is documented in Jorgenson, Ho, and Samuels (2012). Previous EU KLEMS datasets limit their sample period to 1970-2010.

<sup>4</sup>Huang, Chapman, and Butry (2009) review various alternative explanations which, among others, rely on insufficient R&D spending in construction, the typical labor-intensive nature of construction projects, and ongoing shortage of skilled workers.

<sup>5</sup>Baumol applies the idea of cost disease to services as education, health care, and performing arts, see for example Baumol (1967), Baumol and Bowen (1965) and Baumol, Blackman, and Wolff (1985). Also, there is some recent evidence which documents that the Baumol cost disease can be at work in various sectors of the United States. Nordhaus (2008) uses industry-level data for the period 1948-2001 and finds that technologically stagnant sectors have rising relative prices. Moro and Nuño (2012) provide evidence of a Baumol cost disease in the US construction industry by showing that TFP differences between construction and the general economy can account for the relative price of construction over the period 1970-2007. They also find a similar pattern for Germany, United Kingdom and Spain.

Using OECD industry-level data I also document that over the last decades productivity slowdowns in construction have occurred in several other economies around the world. I exploit this cross-sectional variation for better identifying my proposed mechanism. An estimated Panel VAR with sign restrictions for 19 OECD economies provides empirical support to the idea that falls in relative productivity of construction may account for recent developments in the housing cycle and current account. To further shed light on the role of this mechanism, I also exploit OECD cross-country data to calibrate the model for each economy under study (*in progress*). Preliminary findings show that: (*i*) construction is on average a relatively labor-intensive sector; (*ii*) countries with higher labor share in construction feature stronger productivity slowdowns. These facts can help to identify the triggering sources of the productivity slowdowns in construction across economies.

**Related literature.** This paper relates to the literature which studies the determinants of the last US housing boom. Most of the literature concentrates on the role of demand factors associated to the extraordinary credit expansion observed in the US over the last decades. For instance, Justiniano, Primiceri, and Tambalotti (2014) emphasize the role of low borrowing rates associated to a global savings glut. They use a quantitative equilibrium model with houses, collateralized debt and foreign borrowing to show that US capital inflows account for between one fourth and one third of the increase in US house prices over the period 1998-2006.<sup>6</sup> Iacoviello and Neri (2010) explicitly consider the role of changing sectoral technologies versus other traditional factors such as shifts in preferences for housing or the role of the monetary policy. They estimate a DSGE model for a closed economy in the spirit of Smets and Wouters (2007) with housing, trade of bonds between heterogeneous households as in Iacoviello (2005), and heterogeneous sectoral productivities, to show that although sectoral productivities can account for the long-run trend in house prices, they cannot account for the positive correlation between housing prices and housing investment observed in the data.<sup>7</sup> In this paper I show that

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<sup>6</sup>Other works which relate to the idea of a global savings glut are Himmelberg, Mayer, and Sinai (2005), Adam, Kuang, and Marcet (2011) and Ferrero (2012). Alternatively, Favilukis, Kohn, Ludvigson, and Van Nieuwerburgh (2012) argue that the key causal factor to drive the boom and bust in US house prices was a financial market liberalization and its reversal.

<sup>7</sup>In this respect, Davis and Heathcote (2005) employ a standard multi-sector neoclassical growth model with housing to explain why housing investment is more volatile than non-housing investment.

developments in sectoral technologies, by interacting with a low borrowing interest rate, can account for the contemporaneous increases in housing prices and housing investment of the early 2000's. Hence the positive correlation between housing prices and residential investment, which has been traditionally associated to shocks arising from the housing demand, here is due to changes in sectoral technologies.<sup>8</sup> The key ingredient to obtain this result is the presence of a low interest rate at which domestic households can borrow from the rest of the world.

This paper also links to the recent strand of the literature which emphasizes the role of fluctuations in the price of land for the housing cycle. For instance, Liu, Wang, and Zha (2013) among others document for the US the boom in land prices over the early 2000's. Davis and Heathcote (2007) document that the bulk of fluctuations in US house prices is due to movements in the price of land, and that land prices are roughly twice as volatile as house prices. Here sectoral productivities, combined with a low borrowing interest rate, explain about 80 percent of the recent surge in land prices, and generate land prices which are roughly twice as much volatile as house prices. Without this interaction, the model cannot generate strong surges in the price of land, and volatilities of the prices of houses and land are *counterfactually* similar.

This paper relates to Ferrero (2012), which shows that domestic factors, such as credit and preference shocks, can generate a negative correlation between house prices and current account balances when interest rates are low. Here a domestic factor identified by the productivity slowdown in construction, combined with a low interest rate, can generate increases in house prices and capital inflows. In particular, the model predicts about 45 percent of the worsening of the US current account over the early 2000's.

This paper shows that a DSGE model featuring only sectoral productivity shocks can account for a substantial part of the recent developments of US house prices. Of course, the model omits other factors which have likely played an important role in shaping the

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Such model predicts that sectoral technologies can account for the long-run trend in house prices, but it delivers a counterfactual negative correlation between housing prices and housing investment.

<sup>8</sup>In particular, Iacoviello and Neri (2010) find that a substantial component of the housing cycle can be explained by exogenous preference shifts towards housing. However Iacoviello (2010) points out that whether housing preference shocks are primitive and interpretable remains an open issue and suggests for further research on their determinants.

US housing cycle, such as the role of monetary policy or changing credit conditions. For instance, the model understates the housing bust in 2007 presumably because it abstracts from financial shocks. Already Jermann and Quadrini (2012) and Gilchrist and Zakrajčák (2012) have shown that the triggering source of the recent crisis can be identified in a large negative financial shock which has led to a credit crunch and sharp falls in economic activity and house prices.<sup>9</sup>

The structure of the paper is as follows. Section 2 provides the motivating evidence. Section 3 describes the model. Section 4 describes the quantitative analysis and reports the results. Section 5 covers the international evidence. Section 6 concludes.

## 2 Motivating Evidence

### 2.1 Productivity Developments in US Construction

Left panel of Figure 1 reports the annual time series of Total Factor Productivity (TFP) in construction and the rest of the economy over the period 1947-2010. In the earlier part of the sample, productivity in construction rapidly grows relative to the rest of the economy: over the years 1947-1967 the average annual productivity growth in construction is about 3.2 percent, while the same figure for the rest of the economy is about 0.5 percent. This pattern changes around the end of the 1960's: productivity in construction abruptly slows down and since then it falls at an average annual rate of about 2.1 percent per year.

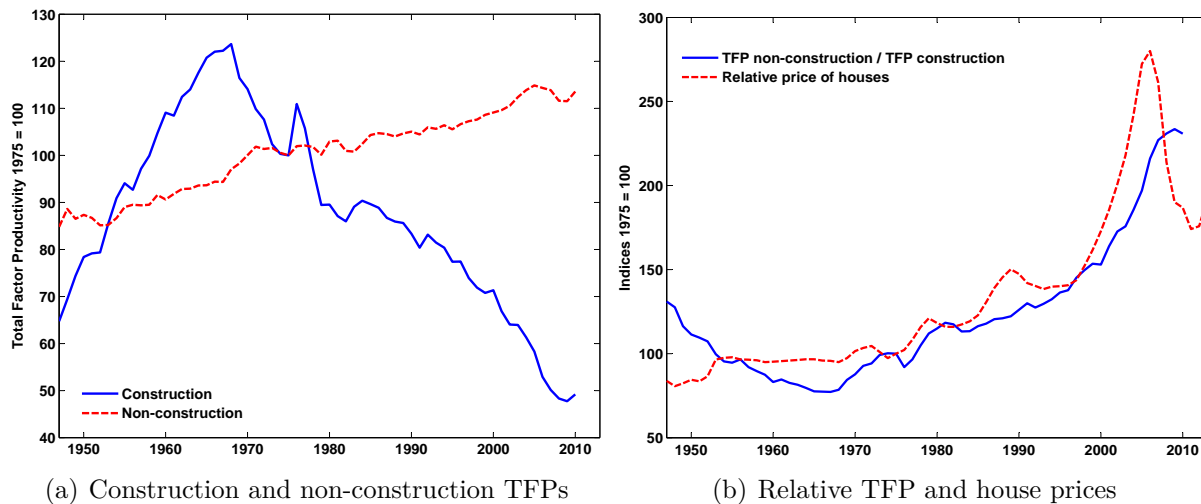
This fall in productivity in construction relative to the rest of the economy has already been emphasized and debated among practitioners and scholars.<sup>10</sup> Why did the productivity slowdown in construction occur? Although I do not provide an answer to

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<sup>9</sup>Moreover, Iacoviello and Neri (2010) show that monetary factors fully account for the bust in residential investment and house prices, while sectoral technologies have no role.

<sup>10</sup>Using data compiled by the Bureau of Labor Statistics (BLS), Baily, Gordon, and Solow (1981) document that labor productivity in construction grew more rapidly than in manufacturing and services between 1948 and 1968, and it was falling between 1968 and 1978 while at the same time productivity in the rest of the economy was growing. This fact has been confirmed by Allen (1985), which documents that productivity in construction reached a peak in 1968 and, except for a brief and small upturn between 1974 and 1976, has been gradually falling over time. In particular, real value added per hour in construction rose at about 2.2 percent per year between 1950 and 1968, while it fell at about 2.4 percent per year between 1968 and 1978. Many other studies have documented that US construction is a relatively low productive sector, see for example Huang, Chapman, and Butry (2009), Corrado, Lengermann, Bartelsman, and Joseph (2006) and Kehoe, Ruhl, and Steinberg (2013).

Figure 1: US Sectoral Productivities and Relative Price of Houses, 1947-2010



*Notes:* data on nominal house prices are from Shiller (2005), on productivities are from EU KLEMS. Nominal house prices are deflated using a PCE-based price index which excludes "Housing and utilities". Weights for constructing the price index are based on PCE expenditure shares. PCE prices and expenditures are from BEA.

this question, there is a large civil engineering literature addressing this phenomenon. For instance, Allen (1985) argues that the factor which triggered the decline in construction productivity was a shift in the mix of construction output from large-scale commercial and industrial projects to residential single-family construction projects which are relatively less intensive in skilled labor. The author documents that between 1967 and 1977 the share of single-family homes in output increased from 20 percent to 26 percent, while shares of industrial and educational buildings declined at the same time.<sup>11</sup> Such a shift in the mix of construction output results in a decline of measured productivity simply because relatively lowly productive sectors receive greater weight at the expenses of highly productive sectors. Huang, Chapman, and Butry (2009) review alternative explanations for this productivity slowdown which, among others, rely on insufficient R&D spending, the labor-intensive nature of construction projects, and an ongoing shortage of skilled workers.<sup>12</sup>

<sup>11</sup>Using Census Bureau data on value of construction put in place I confirm this finding and also document that such trend persists until the early 2000's, see Figure 9 in Appendix. Data end in 2002 due to a discontinuity in the series.

<sup>12</sup>Teicholz, Goodrum, and Haas (2001), Teicholz (2004), and Teicholz (2013) emphasize the lack of R&D spending in construction. Stokes (1981) points out a deceleration in growth of capital per worker. Practitioners in the construction sector agree on an ongoing shortage of skilled workers presumably due



Right panel of Figure 1 plots the ratio of TFP in non-construction over TFP in construction and the relative price of houses.<sup>13</sup> Relative TFP falls over the 1940's - 1960's while at the same time the relative price of houses is relatively stable. By the end of the 1960's relative TFP and house prices start to grow over time. House prices subsequently rise by about 70 percent over the period 1995-2006, and abruptly fall over the bust in 2007-2009. The recent boom and bust of US house prices has already been emphasized in the literature, see for example Favilukis, Kohn, Ludvigson, and Van Nieuwerburgh (2012) and Justiniano, Primiceri, and Tambalotti (2014). Here I emphasize the remarkable comovement between relative productivities and relative house prices.<sup>14</sup>

The evidence of a productivity slowdown in construction relative to the rest of the economy is robust to other standard productivity measures as shown in left panel of Figure 2, which also plots relative productivities computed using real value added over number of employees and real value added over hours worked. Moreover, the US financial sector experienced a dramatic expansion since the early 1970's which could have driven the productivity slowdown in construction. Right panel of Figure 2 plots relative productivities computed by excluding the Finance, Insurance, and Real Estate (F.I.R.E.) sectors, and results are robust.

Data on sectoral productivities come from a novel EU KLEMS dataset documented in Jorgenson, Ho, and Samuels (2012) which spans the period 1947-2010, unlike previous EU KLEMS versions which begin on 1970. I also employ alternative data sources to document this productivity slowdown. Specifically, I compute sectoral labor productivities by using data on real value added from Bureau of Economic Analysis (BEA) and on employment from Bureau of Labor Statistics (BLS). Data are available until 2013. Left panel of Figure 3 plots the resulting series with the corresponding ones constructed with EU KLEMS data.

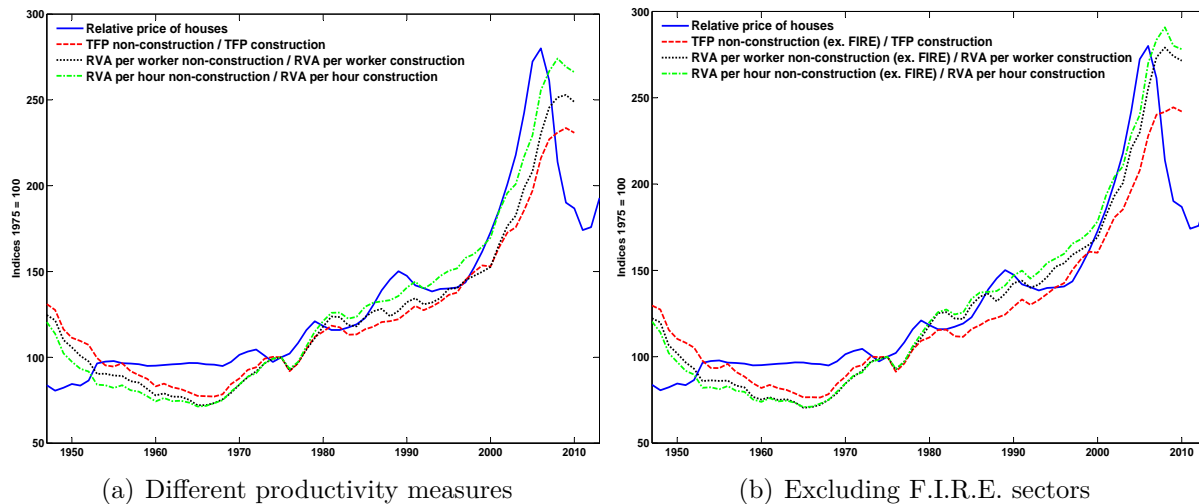
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to declining real wages and unionization rates, see CII (2003).

<sup>13</sup>The relative price of houses is constructed as the ratio of nominal house prices from Shiller (2005) over a price index for non-housing goods and services. The price index for non-housing goods and services is constructed by aggregating series on price indices from Personal Consumption Expenditures (BEA) and by excluding the line "Housing and utilities". Weights are based on time-varying expenditure shares.

<sup>14</sup>Importantly, it would be more appropriate to link the relative price of houses to a measure of relative productivity in *residential* construction. Unfortunately, disaggregated productivity series by subcomponent of the construction sector are not available for the full sample period considered here. Previous works in the literature provided evidence that residential projects are typically less productive than other types of construction projects, so if disaggregated data were available it would even strengthen my results.

Figure 2: US Sectoral Productivities and Relative Price of Houses: Robustness

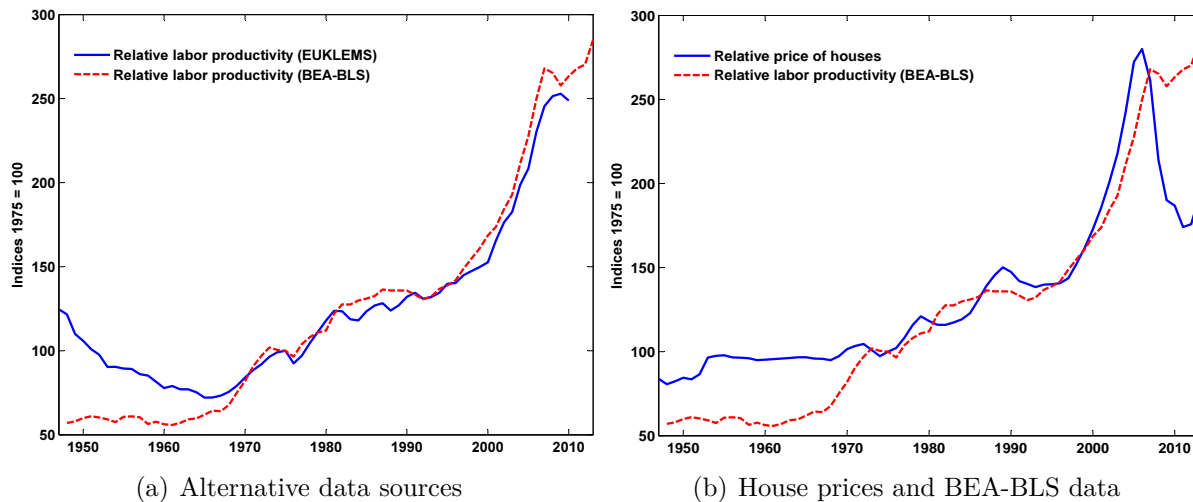


Notes: data on nominal house prices are from Shiller (2005), on productivities are from EU KLEMS. Nominal house prices are deflated using a PCE-based price index which excludes "Housing and utilities". Weights for constructing the price index are based on PCE expenditure shares. PCE prices and expenditures are from BEA.

The two productivity measures are approximately similar, apart from a discrepancy over the earlier part of the sample: according to the alternative measure based on BEA and BLS data, the construction sector grows approximately at the same rate of the economy over the 1950's. Despite this discrepancy, the productivity slowdown in construction is evident also using BEA-BLS data. Right panel of Figure 3 shows that relative labor productivity markedly comoves with the relative housing price. Interestingly, the graph shows that (i) still there is no sign that the productivity slowdown in construction has ended, and (ii) house prices rapidly pick up after the bust of the last recession.

Finally, the caveat to make here is that standard productivity measures exclude land from calculation due to problems in measuring its input value in production, see for example Schreyer and Pilat (2001) and Diewert (2000). Hence in principle standard sectoral productivity measures could be affected by changes in the price of land. Given the specificity of the construction industry in relying on land as input of production, one may think that an abrupt spike in land prices could have triggered the productivity slowdown in construction. I estimate sectoral TFP series which net out the role of the price of land. The estimation strategy relies on two ingredients: (i) a structural model

Figure 3: US Sectoral Productivities and Relative Price of Houses: BEA-BLS Data



Notes: data on nominal house prices are from Shiller (2005), on productivities are from EU KLEMS, BEA, and BLS. Nominal house prices are deflated using a PCE-based price index which excludes "Housing and utilities". Weights for constructing the price index are based on PCE expenditure shares. PCE prices and expenditures are from BEA.

in which sectoral output is a Cobb-Douglas in capital, labor and land as in Iacoviello and Neri (2010); (ii) estimated series of the price of land from Davis and Heathcote (2007). Details on the estimation strategy are in Section C in Appendix. Figure 10 in Appendix plots the original EU KLEMS TFP series for construction, non-construction, and their ratio jointly with land-price filtered TFP series. Once dealing with the price of land in measured TFP, the ratio of non-construction TFP versus construction TFP is lower, especially after the 1990's. However the qualitative results are unchanged: there is evidence of a productivity slowdown in construction relative to other sectors which started around the end of the 1960's and still persists.<sup>15</sup>

## 2.2 US States Panel Evidence

This section documents using a panel of US States data that over the period 2000-2011 relative productivity in construction significantly explains house prices even after control-

<sup>15</sup>Importantly, these estimates could overstate the role of land in production. While land does not directly enter as a main factor of production in standard sectoral productivities, it can be implicitly taken into account through the contribution of capital under the subcomponent *Residential structures*. According to EU KLEMS, capital stock is the sum of the following subcomponents: Computing equipment; Communication equipment; Software; Transport equipment; Other machinery and equipment; Total non-residential investment; Residential structures; Other assets.

ling for other key factors such as households leverage and land prices. Data are at annual frequency at the US State level on house prices, sectoral labor productivities, household debt per capita, and land prices.<sup>16</sup> The following model is estimated

$$\Delta HousePrices_{i,t} = \beta \Delta RelProdConstruction_{i,t} + \gamma' X_{i,t} + \alpha_i + \delta t + \varepsilon_{i,t}$$

where  $i$  and  $t$  respectively index states and time. The main dependent variable is the annual change in real logged house prices. The regressor of interest is the change in logged labor productivity in construction relative to overall productivity, where sectoral labor productivity is measured as real value added over number of employees. Vector  $X_{i,t}$  includes other State-specific controls: the change in logged real household debt per capita, and the change in logged real land prices. It has already been emphasized in the literature that credit conditions have had a role in the recent US house price boom, see for example Favilukis, Kohn, Ludvigson, and Van Nieuwerburgh (2012), Mian and Sufi (2009) and Justiniano, Primiceri, and Tambalotti (2014). Recent literature has also pointed out the role of residential land prices for fluctuations in house prices, for example in Davis and Heathcote (2005) and Davis and Heathcote (2007). All variables are in real terms and deflated using the US Consumer Price Index. The baseline set of regressions amounts to standard panel fixed effect estimations. Then to account for persistency in growth rates of house prices, similar regressions are conducted by including a lag of the dependent variable and by employing the estimator developed in Arellano and Bond (1991).

Table 6 in Appendix reports findings. Columns (1) and (2) refer to the panel fixed effect estimation which just includes relative productivity in construction, without and with a time trend. In columns (3) to (6) other controls are sequentially added. All standard errors are clustered at the State level. Columns (7) to (12) report the dynamic panel estimation results, in which one lag of the dependent variable is added as additional regressor. The dynamic-panel estimator (the two-step version) employs lags of the dependent and regressors up to  $t-6$ , to guarantee instruments' exogeneity with respect to the error of

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<sup>16</sup>US State level data on house prices are from FHFA; on sectoral labor productivities are from BEA and BLS; on household debt per capita from the Federal Reserve Bank of New York; data on land prices are from Davis and Heathcote (2007), see Land and Property Values in the US, Lincoln Institute of Land Policy <http://www.lincolnst.edu/resources/>. See Section E in Appendix for further details about the data.

the differenced equation. Heteroskedasticity-robust standard errors are computed. Coefficient estimates of relative productivity in construction, household debt and land prices have right sign and are strongly significant in all specifications. These figures provide suggestive evidence but have not a causal interpretation. In column (1) an increase of one percent in growth of relative productivity in construction is associated to a decrease of about -0.647 percentage points in growth of house prices. Productivity alone explains about 26 percent of variation in house prices, and around 46 percent when including a trend. By including household debt per capita, the fraction of explained variance goes to 46 percent and 52 percent respectively without and with time trend. The inclusion of land prices surprisingly does not lead to a sizable increase in the fraction of explained variance, which is about 49 percent and 54 percent respectively without and with trend. In terms of magnitude of the coefficient estimates, dynamic panel data regressions yield comparable results, even though just regressions (9) and (11) satisfy the validity conditions of the Arellano-Bond estimator. In columns (10) and (12) the Arellano-Bond test rejects the hypothesis that the error term is uncorrelated with the instruments, while in columns (7) and (8) the Hansen  $J$  test rejects the null that all moment conditions are jointly valid.<sup>17</sup> The same battery of regressions is performed by employing series of house prices made available in Davis and Heathcote (2007). Table 7 in Appendix summarizes results which support previous findings.

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<sup>17</sup>Two conditions have to be met: first, instruments should be uncorrelated with the error term, which amounts to a non-rejection of the null of the Arellano-Bond test; second, all moment conditions should be jointly valid, which amounts to a non-rejection of the null of the Hansen  $J$  test.

## 3 The Model

### 3.1 Assumptions

I consider an open economy with two sectors  $i = S, N$ , where each sector is populated by identical perfectly competitive firms. Firms in the construction sector  $i = S$  produce structures which are nontradable, depreciate at rate  $\delta_s$ , and are used as input in the production of houses. Firms in the non-construction sector  $i = N$  produce a tradable nondurable non-housing good which can be consumed or used for investment in physical capital. The non-housing good and structures are respectively produced using two constant-returns-to-scale production functions

$$y_{it} = A_{it}k_{it}^{\alpha_i}e_{it}^{1-\alpha_i} \quad i = N, S \quad (1)$$

where  $y_i$ ,  $k_i$  and  $e_i$  denote sector- $i$  output, capital and labor,  $0 < \alpha_i < 1$  is the sector- $i$  capital share, and  $A_i$  is the exogenous Hicks-neutral technology (TFP hereafter) in sector  $i$ . Capital and labor are freely mobile across the two sectors. Let  $Z_t = A_{Nt}/A_{St}$  be the relative TFP of non-construction versus construction and normalize  $A_{St} \equiv 1$  for all  $t$ . An increase in  $Z_t$  can be thought of as arising either from an increase in productivity of the non-construction sector or from a decrease in productivity of construction. Relative TFP is exogenous, and evolves according to the following law of motion

$$Z_t = Z_0(1 + \gamma_Z)^t e^{z_t} \quad (2)$$

where  $Z_0$  is a constant,  $\gamma_Z$  is the net trend growth rate assumed to be time-invariant, while  $z_t$  is a stochastic component which evolves as

$$z_t = \rho_z z_{t-1} + \varepsilon_{zt} \quad (3)$$

where  $0 < \rho_z < 1$  is the autocorrelation coefficient and  $\varepsilon_{zt}$  are serially uncorrelated zero-mean identically distributed shocks.

As in Davis and Heathcote (2005) there is a continuum of identical perfectly competitive real estate developers which combine structures and land to produce new houses. Land and houses are nontradable. New houses are produced according to the following

constant-returns-to-scale production function

$$y_{ht} = l_t^\phi s_t^{1-\phi} \quad (4)$$

where  $y_{ht}$  denotes the quantity of new houses produced,  $l_t$  and  $s_t$  are respectively the inputs of land and structures, and  $\phi$  is the share of land in production of new houses. Real estate developers do not add value added in production. Land does not depreciate, hence Davis and Heathcote (2005) show that houses depreciate at rate

$$1 - \delta_h = (1 - \delta_s)^{1-\phi} \quad (5)$$

There exists an infinitely lived representative household with preferences over the non-housing good  $c_t$  and houses  $h_t$  given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \log c_t^\gamma h_t^{1-\gamma} \quad (6)$$

where  $0 < \beta < 1$  is the subjective discount factor. Non-housing good and houses enter in the utility function as a Cobb-Douglas bundle where  $0 < \gamma < 1$  is the share of non-housing good. This assumption implies that the ratio of expenditures in non-housing good over housing expenditures is constant over time, which is broadly in line with what is observed in the US over the last decades, as discussed in Davis and Heathcote (2005).<sup>18</sup> The household is endowed with one unit of productive time, and for simplicity the household uses that unit of time by inelastically supplying labor to firms. The household is also endowed with an initial stock of physical capital  $k_t$ , an initial stock of houses  $h_t$ , an initial stock of foreign debt  $d_t$ . As in Davis and Heathcote (2005) the household also receives at every period a constant acreage of new land  $\bar{l}$ . The household sells this amount of land to real estate developers which incorporate it in new produced houses. The assumption that land increases at a fixed rate captures as a reduced form all factors which may affect the stock of buildable land, such as the expansion of urban growth boundaries. The income of the household derives from supplying labor to firms, from renting out capital, and from selling land to real estate developers. The household consumes her income in non-housing

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<sup>18</sup>Many authors have employed this formulation, for instance in Iacoviello (2005), Campbell and Hercowitz (2009) and Justiniano, Primiceri, and Tambalotti (2014).

good expenditures, investing in new capital that will be rented out next period, and in new housing that will be occupied next period.

The household can borrow from the rest of the world at an exogenous internationally fixed interest rate  $r^*$ . The borrowing rate is assumed to be so low that the household finds always optimal to borrow from the rest of the world as long as her collateral constraint (to-be-defined) does not bind. The borrowing rate is low due to a virtually unlimited demand of US securities by the rest of the world, which is reminiscent of the *global savings glut* hypothesis proposed by Bernanke (2005).<sup>19</sup> The household inherits a stock of foreign debt  $d_t$  from previous period and has to decide how much debt to repay  $x_t$ , which determines next period debt as

$$d_{t+1} = (1 + r^*)d_t - x_t \quad (7)$$

Debt is priced in terms of the non-housing good. A positive value for  $d$  implies that the representative household is net debtor with respect to the rest of the world, and viceversa if negative.

The per-period budget constraint of the household reads

$$c_t + i_{kt} + p_{ht}i_{ht} - d_{t+1} = w_t + r_t k_t + p_{lt}\bar{l} - (1 + r^*)d_t \quad (8)$$

where  $i_{kt}$  and  $i_{ht}$  denote investment in respectively capital and houses,  $p_{ht}$  and  $p_{lt}$  denote the relative prices of houses and land, while  $w_t$  and  $r_t$  are the wage rate and the rental rate of capital. The stock of houses evolves according to the following equation

$$h_{t+1} = (1 - \delta_h)h_t + i_{ht} \quad (9)$$

where  $0 < \delta_h < 1$  is the depreciation rate of houses. Implicitly, investing in new houses implies some adjustment costs because increments in the supply of land are fixed. Capital evolves according to the following law of motion

$$k_{t+1} = (1 - \delta_k)k_t + \left(1 - \Phi\left(\frac{i_{kt}}{i_{kt-1}}\right)\right) i_{kt} \quad (10)$$

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<sup>19</sup>This way of modeling the global savings glut is similar in spirit to Boz and Mendoza (2014) and Garriga, Manuelli, and Peralta-Alva (2012). Alternatively, Justiniano, Primiceri, and Tambalotti (2014) model a global savings glut by taking the observed US trade deficit as an exogenous driving force. Moreover, Kehoe, Ruhl, and Steinberg (2013) capture a global savings glut by explicitly modeling the rest of the world and by assuming that foreigners are relatively less impatient than the domestic household.



where  $0 < \delta_k < 1$  is the depreciation rate of capital and the function  $\Phi$  represents investment adjustment costs as in Christiano, Eichenbaum, and Evans (2005). As it will be shown in the quantitative section, these adjustment costs are a key ingredient to allow for a positive correlation between house prices and the share of residential investment in GDP.

Borrowing of the household is limited by the following constraint,

$$\theta\beta E_t(p_{ht+1}h_{t+1}) \geq d_{t+1} \quad (11)$$

which states that the amount of foreign debt chosen by the household cannot exceed a fraction  $\theta$  of the expected discounted value of her housing stock. Hence houses are valuable to the household not only due to the housing services they provide, but also because they can be used as collateral against borrowing from the rest of the world.<sup>20</sup>

### 3.2 Equilibrium

The representative firm in sector  $i$  takes as given prices and chooses the amounts of capital and labor to employ in production so to maximize profits. The first-order conditions for the non-construction firm are given by

$$(1 - \alpha_N)Z_t k_{Nt}^{\alpha_N} e_{Nt}^{-\alpha_N} = w_t \quad (12)$$

$$\alpha_N Z_t k_{Nt}^{\alpha_N - 1} e_{Nt}^{1 - \alpha_N} = r_t \quad (13)$$

The first-order conditions for the construction firm are given by

$$(1 - \alpha_S)p_{st}k_{st}^{\alpha_S} e_{st}^{-\alpha_S} = w_t \quad (14)$$

$$\alpha_S p_{st} k_{st}^{\alpha_S - 1} e_{st}^{1 - \alpha_S} = r_t \quad (15)$$

These conditions equate the marginal product of each factor to its marginal cost in each sector.

The representative real estate developer takes as given prices and chooses the amounts of land and structures to employ in order to maximize profits. The first-order conditions

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<sup>20</sup>The formulation of the financial constraint in (11) is a simplified version of the constraint in Justiniano, Primiceri, and Tambalotti (2014), and is similar in spirit to those in Mendoza (2002), Bianchi (2011) and Bianchi and Mendoza (2011), Garriga, Manuelli, and Peralta-Alva (2012) among others.

are given by

$$\phi p_{ht} l_t^{\phi-1} s_t^{1-\phi} = p_{lt} \quad (16)$$

$$(1 - \phi) p_{ht} l_t^{\phi} s_t^{-\phi} = p_{st} \quad (17)$$

which equate the marginal products of land and structures to their respective marginal costs.

For given initial conditions on the stocks of capital, houses and foreign debt, and by taking prices as given, the representative household chooses the amount of consumption of the non-housing good, investment in capital and houses, the new level of capital and foreign debt so to maximize the present value of its instantaneous utility (6) subject to the budget constraint, the financial constraint, and the laws of motion of stocks of foreign debt, houses and capital. The first-order conditions are

$$(c_t) \quad \frac{\gamma}{c_t} = \lambda_t \quad (18)$$

$$(k_{t+1}) \quad q_t = \beta E_t \left[ \frac{\lambda_{t+1}}{\lambda_t} (q_{t+1} (1 - \delta_k) + r_{t+1}) \right] \quad (19)$$

$$(i_{kt}) \quad 1 = q_t \left( 1 - \Phi_t - \frac{i_{kt}}{i_{kt-1}} \Phi'_t \right) + \beta E_t \left[ \frac{\lambda_{t+1}}{\lambda_t} q_{t+1} \frac{i_{kt+1}}{i_{kt}} \Phi'_{t+1} \right] \quad (20)$$

$$(d_{t+1}) \quad \lambda_t (1 - \theta \eta_t) = \beta (1 + r^*) E_t (\lambda_{t+1}) \quad (21)$$

$$(i_{ht}) \quad \lambda_t p_{ht} = \beta E_t \left[ \frac{1 - \gamma}{h_{t+1}} + (1 - \delta_h) \lambda_{t+1} p_{ht+1} + \lambda_{t+1} \theta \eta_{t+1} p_{ht+1} \right] \quad (22)$$

where  $\lambda_t$  is the nonnegative Lagrange multiplier on the budget constraint,  $\eta_t$  is the nonnegative Lagrange multiplier on the financial constraint (11), and  $\Phi_t \equiv \Phi \left( \frac{i_{kt}}{i_{kt-1}} \right)$ . Condition (19) equates the marginal cost (in utils) of investing in physical capital to its marginal utility, where  $q_t$  is the relative price of capital. Condition (21) states that the marginal cost of foreign debt has to be equal to its marginal utility, while condition (22) equates the marginal cost of investing in housing to its marginal utility.

For given sequence of the exogenous state  $Z_t$ , an equilibrium in this economy will be

- a sequence of allocations  $\{c_t, i_{kt}, i_{ht}, d_t, x_t, k_t, h_t, k_{Nt}, k_{St}, e_{Nt}, e_{St}, y_{Nt}, y_{St}, y_{ht}\}_{t=0}^{\infty}$
- and a sequence of prices  $\{p_{ht}, p_{st}, p_{lt}, r_t, w_t, q_t\}_{t=0}^{\infty}$

such that

1. The sequence  $\{c_t, k_{t+1}, i_{kt}, i_{ht}, d_t\}$  solves the problem of the household
2. The pairs  $\{k_{it}, e_{it}\}$  solve the problem of the firm in each sector  $i = N, S$
3. The pair  $\{l_t, s_t\}$  solves the problem of the real estate developer
4. The market of the non-housing good clears

$$c_t + i_{kt} + x_t = y_{Nt} \quad (23)$$

5. The market of houses clears:

$$i_{ht} = y_{ht} \quad (24)$$

6. The market of structures clears:

$$s_t = y_{St} \quad (25)$$

7. The market of new land clears:

$$l_t = \bar{l} \quad (26)$$

8. The market of capital clears:

$$k_{Nt} + k_{St} = k_t \quad (27)$$

9. The market of labor clears:

$$e_{Nt} + e_{St} = 1 \quad (28)$$

and the laws of motion of debt, houses and capital hold, as well as the financial constraint. The aggregate resource constraint of the economy can be obtained by combining the market clearing conditions for non-housing good and houses,

$$c_t + i_{kt} + p_{ht}i_{ht} + x_t = y_{Nt} + p_{ht}y_{ht} \quad (29)$$

which states that the sum of expenditures in non-housing good, non-residential and residential investment, and debt repayments, has to be equal to the total value produced in

the economy. Moreover,  $GDP$  is defined as the right-hand side of equation (29), which is denoted as  $y_t$

$$y_t \equiv y_{Nt} + p_{ht}y_{ht} \quad (30)$$

From the aggregate resource constraint, equilibrium debt repayments  $x_t$  coincide with net exports. The current account balance can be defined as

$$CA_t \equiv -d_{t+1} + d_t \quad (31)$$

$$= x_t - r^*d_t \quad (32)$$

which is equal to net exports minus the current servicing of debt.<sup>21</sup>

### 3.3 House Prices, Sectoral Productivities and Low Interest Rate

This section shows how equilibrium house prices are related to sectoral productivities and a low interest rate. By combining the optimal demands of land and structures with the Cobb-Douglas production technology of houses, house prices are linked to prices of land and structures via the following equation,

$$p_{ht} = \frac{p_{lt}^\phi p_{st}^{1-\phi}}{\phi^\phi (1-\phi)^{1-\phi}} \quad (33)$$

and by taking logs and first differences,

$$\Delta \ln p_{ht} = \phi \Delta \ln p_{lt} + (1-\phi) \Delta \ln p_{st} \quad (34)$$

Since houses are a bundle of structures and land, changes in house prices are averages of changes in prices of land and structures, weighed by the share of land in housing production  $\phi$ . From the optimality conditions of firms in construction and non-construction, marginal products of labor and capital equalize across sectors,

$$(1-\alpha_N)Z_t \left( \frac{k_{Nt}}{e_{Nt}} \right)^{\alpha_N} = (1-\alpha_S)p_{st} \left( \frac{k_{St}}{e_{St}} \right)^{\alpha_S} \quad (35)$$

$$\alpha_N Z_t \left( \frac{k_{Nt}}{e_{Nt}} \right)^{\alpha_N-1} = \alpha_S p_{st} \left( \frac{k_{St}}{e_{St}} \right)^{\alpha_S-1} \quad (36)$$

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<sup>21</sup>The model can deliver predictions on net capital flows between the domestic economy and the rest of the world, but it is silent about the behavior of *gross* capital flows, which as documented in Broner, Didier, Erce, and Schmukler (2013) they interact with the business cycle as well as during financial crises.

Since there is frictionless sectoral reallocation of factors, in equilibrium there are unique factor markets and hence unique prices of labor and capital,  $w_t$  and  $r_t$ . By dividing side by side (35) and (36) we can see that the sector with the lowest capital share in production displays the lowest capital-labor ratio,

$$\left(\frac{1 - \alpha_N}{\alpha_N}\right) \frac{k_{Nt}}{e_{Nt}} = \left(\frac{1 - \alpha_S}{\alpha_S}\right) \frac{k_{St}}{e_{St}} \quad (37)$$

In the data, the capital share of construction is lower than average, see for example Davis and Heathcote (2005) and Acemoglu and Guerrieri (2008). Hereafter it is assumed to be the case,  $\alpha_S < \alpha_N$ . By combining equations (35), (36), and (37), the price of structures is a function of the relative productivities and the rental rate of capital,

$$p_{st} = \Psi Z_t^{\frac{1-\alpha_S}{1-\alpha_N}} r_t^{\frac{\alpha_S-\alpha_N}{1-\alpha_N}} \quad (38)$$

where  $\Psi$  is function just of  $\alpha_S$  and  $\alpha_N$ , and by taking logs and first differences,

$$\Delta \ln p_{st} = \frac{1 - \alpha_S}{1 - \alpha_N} \Delta \ln Z_t - \frac{\alpha_N - \alpha_S}{1 - \alpha_N} \Delta \ln r_t \quad (39)$$

A productivity slowdown in construction, captured by an increase in  $Z$ , positively affects the price of structures. The effect is amplified the lower is the capital share in construction and the higher is the capital share in non-construction. The mechanism works through the traditional competition in markets for factors. Prices of labor and capital are set according to marginal productivities of the most productive sector, so relative productivity increases in the most productive sector increase costs for the least productive sector which eventually commands higher price. Baumol (1967) emphasizes this mechanism and predicts that stagnant sectors, in the sense that their productivity grows at a lower rate than the rest of the economy, suffer from a *cost disease* which leads to increases in costs, and thus in prices, above the average of the economy.

The price of structures also depends on the rental rate of capital as long as there are differences in capital shares across sector. The intuition is that given sectoral heterogeneities in factor intensities, reallocation of factors implies an excess of demand or supply of capital which is zeroed through a change in the rental price of capital, which in turn affects construction costs, and eventually the price of structures.

By combining the optimal demand for land with the market clearing conditions, the relative price of land is an increasing function of both the price of houses and residential investment, and is a decreasing function of new available land,

$$p_{lt} = \phi \frac{p_{ht} i_{ht}}{\bar{l}} \quad (40)$$

By taking logs and first differences, the growth in the price of land depends on growths in the price of houses and residential investment,

$$\Delta \ln p_{lt} = \Delta \ln p_{ht} + \Delta \ln i_{ht} \quad (41)$$

By combining equations (34), (39) and (41), changes in the price of houses depend on changes of the price of structures and of residential investment via the share of land in production  $\phi$ ,

$$\Delta \ln p_{ht} = \Delta \ln p_{st} + \frac{\phi}{1 - \phi} \Delta \ln i_{ht} \quad (42)$$

Since new increments of land are fixed, producing more houses involves increasing costs.<sup>22</sup> A productivity slowdown in construction positively affects the price of houses via two channels. First, it increases the price of structures, and since structures are an input in the production of houses, the price of houses increases. This channel operates through the competition in factor markets, and the key ingredient is sectoral heterogeneity in productivities.<sup>23</sup> Second, the productivity slowdown in construction, by increasing house prices, increases the value of real estate which is used as collateral and relaxes the collateral constraint. If the interest rate is sufficiently low, households find optimal to accumulate foreign debt, hence the current account balance deteriorates. These capital inflows lead to a surge in residential investment, which in turn increases the demand for land. The

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<sup>22</sup>As explained in Davis and Heathcote (2005), the intuition is that new structures need to be crammed in a smaller lot of land, this reduces the quantity of housing services delivered by a structure, hence bigger and more expensive structures are required to produce an effective unit of housing services. For example, in cities where the supply of housing is limited by geographical constraints, the only way to create new residential structures is to "stack them vertically" (e.g. sky-scrapers), which necessarily increase the production cost.

<sup>23</sup>In the special case of no land ( $\phi = 0$ ) and equal capital shares across sectors ( $\alpha_S = \alpha_N$ ) the relative price of houses equals relative TFP

$$p_{ht} = Z_t \quad (43)$$

A similar condition can be obtained without capital. See Section D in Appendix.

price of land increases, and the price of houses rises further. This second channel operates only if land is present. Without land in production ( $\phi = 0$ ), residential investment plays no role for the price of houses, and the prices of houses and structures coincide.

## 4 Quantitative Analysis

### 4.1 Solution and Calibration

Since technologies and the utility function have a Cobb-Douglas form, a balanced growth path exists, see for example Ngai and Pissarides (2007) and Davis and Heathcote (2005). Over the deterministic balanced growth path, relative TFP grows at the constant rate  $\gamma_Z$ , while the other endogenous are either constant (such as the real interest rate) or grow at constant rates. Table 1 reports the variable-specific growth rates: importantly, trends in prices of houses, land and structures positively depend on the growth of relative TFP.

Table 1: Growth Rates over the Deterministic Balanced Growth Path

Gross growth rate	Variable
1	$r, e_N, e_S, \eta, l, q$
$1 + \gamma_Z$	$Z$
$(1 + \gamma_Z)^{\frac{1}{1-\alpha_N}}$	$p_l, c, k_N, k_S, k, y, d, y_N, x, w, i_k$
$(1 + \gamma_Z)^{\frac{1-\alpha_S}{1-\alpha_N}}$	$p_s$
$(1 + \gamma_Z)^{\frac{\alpha_S}{1-\alpha_N}}$	$y_S, s$
$(1 + \gamma_Z)^{\frac{\alpha_S(1-\phi)}{1-\alpha_N}}$	$y_h, i_h, h$
$(1 + \gamma_Z)^{\frac{1-\alpha_S(1-\phi)}{1-\alpha_N}}$	$p_h$

In order to find the solution of the model I rescale all variables according to their specific growth rates. For a generic variable  $v_t$  I define

$$\hat{v}_t = \frac{v_t}{(1 + \gamma_v)^t} \quad (44)$$

where  $\hat{v}$  is constant over the deterministic balanced growth path. Derivations of the stationarized equilibrium conditions are in Section B in Appendix. I log-linearize the set

of stationarized equilibrium conditions around the deterministic balanced growth path and I recover the solution of the model. As in Iacoviello and Neri (2010), the solution assumes that the collateral constraint always binds in equilibrium.<sup>24</sup>

I calibrate several parameters to match US data while for others I rely on previous studies. Frequency is yearly. Given that over the balanced growth path relative TFP should grow at constant rate, I simulate the model over the period 1967-2010, in which the relative productivity slowdown in construction is approximately constant. I also show in Section 4.3 that qualitative results are robust to the choice of the sample. I obtain an estimate for the rate of growth of relative TFP via an OLS regression on the postulated law of motion of relative productivities in (2),

$$\ln Z_t = \beta_0 + \beta_1 t + u_t \quad (45)$$

where  $\beta_0 = \ln Z_0$ ,  $\beta_1 = \ln(1 + \gamma_Z)$  and  $u_t = z_t$ . Before estimation, an outlier detection analysis is conducted on the series using the TRAMO/SEATS software of Caporello and Maravall (2011). The procedure detects the observation of 1976 as an outlier affecting the transitory component of the series of construction TFP. Given that previous literature does not provide a clear economic explanation to such spike, I correct for the outlier and Figure 11 plots original and outlier-corrected series. The estimated value for the rate of growth of relative TFP is  $\gamma_Z = 0.0224$ , which implies a growth of about 2.2 percent per year. Davis and Heathcote (2005) find that over the period 1947-2001 productivities in services and manufacturing, relative to construction, respectively grow at rates of about 1.4 and 2.6 percent per year, in between my estimated value. The scale parameter  $Z_0$  is calibrated to normalize the stationarized price of structures to one over the balanced growth path. I estimate the autocorrelation coefficient of the stochastic component of relative TFP ( $z_t$ ) and I find  $\rho_z = 0.95$ . This value implies a high persistent process in line with estimates of previous works.<sup>25</sup> Further, the standard deviation of relative

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<sup>24</sup>This assumption greatly simplifies the solution of the model. In a model with trade of bonds between patient and impatient households as in Iacoviello (2005), Iacoviello and Neri (2010) state that for reasonable values of discount factors of the households, the model with occasionally binding constraint predicts that impatient households are arbitrarily close to the constraint. Further, in a similar framework Liu, Wang, and Zha (2013) show that predictions of a model with occasionally binding constraint are close to those in which the collateral always binds.

<sup>25</sup>Davis and Heathcote (2005) find that the autocorrelation coefficients of the stochastic component of



productivity innovations ( $\varepsilon_{zt}$ ) is  $\sigma_z = 0.026$ .

Sectoral capital shares are obtained from EU KLEMS data on sectoral value added and labor compensation. The capital share in construction is  $\alpha_G = 0.097$ , while for non-construction is  $\alpha_n = 0.315$ . As in Davis and Heathcote (2005), Finance, Insurance, and Real Estate are excluded from non-construction as most of their capital services are imputed rents. Such estimates confirm that the US construction is relatively labor-intensive compared to the rest of the economy. Such values are also in line with values employed in Davis and Heathcote (2005), namely 0.132, 0.309, and 0.237 for respectively construction, manufacturing and services.<sup>26</sup>

Values for the yearly depreciation rates of capital and structures are taken from Davis and Heathcote (2005). The depreciation rate of capital is set to  $\delta_k = 0.0557$ , while the depreciation of structures is  $\delta_s = 0.0157$ , which is also similar to the value employed in Garriga, Manuelli, and Peralta-Alva (2012). The yearly increment of the supply of land  $\bar{l}$  is set to normalize the stationarized price of land to one over the deterministic balanced growth path, which requires  $\bar{l} = 0.023$ .<sup>27</sup> Regarding the parameter governing the share of land in production of new houses  $\phi$ , Davis and Heathcote (2005) use a value of about 10 percent following an unpublished estimate from the Census Bureau, other studies as Iacoviello and Neri (2010) and Kiyotaki, Michaelides, and Nikolov (2011) also use that value. However Davis and Heathcote (2007) estimate that land accounts on average for 36 percent of the value of the aggregate housing stock over the period 1975-2006. I set an intermediate value  $\phi = 0.30$ . Such figure, combined with the value for  $\delta_s$ , imply a depreciation rate for houses  $\delta_h = 0.011$  which is very close to the 0.012 per year employed in Justiniano, Primiceri, and Tambalotti (2014). The function governing the adjustment

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productivity in construction, manufacturing and services are respectively 0.70, 0.87 and 0.92.

<sup>26</sup>For robustness, sectoral capital shares are also estimated using the World Input-Output database Socio-Economic Accounts which provides sectoral data for the period 1995-2009. Resulting values are 0.165 and 0.324 respectively for construction and non-construction. Details on how capital shares are computed are in Section E in Appendix.

<sup>27</sup>The parameter  $\bar{l}$  disappears from the linearized solution of the model, hence it affects just levels of variables over the balanced growth path. The normalization is similar to Davis and Heathcote (2005) which set such parameter to one.

costs to investment in capital is parameterized as follows

$$\Phi(x) = \frac{\psi}{2} [x - (1 + \gamma_{ik})]^2 \quad (46)$$

where  $\psi$  is a parameter strictly greater than zero and  $\gamma_{ik}$  is the growth rate of nonresidential investment over the balanced growth path. Over the deterministic balanced growth path, the function  $\Phi$  is such that  $\Phi = \Phi' = 0$  and  $\Phi'' > 0$ . The value for  $\psi$  is set equal to 2 as in Justiniano, Primiceri, and Tambalotti (2014), following estimates from Eberly, Rebelo, and Vincent (2012).

The specification of the utility function implies unitary inter-temporal elasticity of substitution as in Justiniano, Primiceri, and Tambalotti (2014). The subjective discount factor is set to  $\beta = 0.96$ , a typical value for models at yearly frequency, see for example Greenwood and Hercowitz (1991) and Garriga, Manuelli, and Peralta-Alva (2012). Such value pins down the level of foreign interest rate at which the household is indifferent from borrowing from external investors  $\bar{r}^* = (1 + \gamma_c)/\beta - 1 = 0.076$ , where  $\gamma_c$  is the yearly growth rate of consumption over the balanced growth path. Regarding the foreign interest rate  $r^*$ , Bianchi and Mendoza (2011) use data on US quarterly Treasury bills to estimate a value of about 0.028 per year over the period 1980-2005. Other authors alternatively exploit Treasury rates data at longer maturities, as Justiniano, Primiceri, and Tambalotti (2014) which consider 5-, 7- and 10-year Treasury bills. Here I choose an intermediate solution by matching the average ex-post real interest rate on US one-year Treasury bills over the period 1967-2010, which equals  $r^* = 0.042$ . Such value is well below the threshold at which the households are indifferent from borrowing from the rest of the world, hence in equilibrium the collateral constraint is always binding.

The collateral parameter  $\theta$  is set to 35 percent, which is in between to values employed in Bianchi and Mendoza (2011) and Garriga, Manuelli, and Peralta-Alva (2012), respectively being equal to 30 percent and 50 percent. Finally the share of non-housing consumption is set to match the average employment share in construction sector, which averages 5.6 percent over the sample. The resulting value is  $\gamma = 0.87$ . Table 2 summarizes the calibration.

Table 2: Parameters

	Definition	Source, Target	Value
$\gamma_Z$	Yearly growth of relative TFP	Data 1967-2010	0.022
$Z_0$	BGP value of relative TFP	Normalization	0.90
$\rho_z$	Autocorrelation of relative TFP shock	Data 1967-2010	0.95
$\sigma_z$	Standard deviation of relative TFP shock	Data 1967-2010	0.026
$\alpha_s$	Capital share in construction	Data 1967-2010	0.097
$\alpha_n$	Capital share in non-construction	Data 1967-2010	0.315
$\delta_k$	Depreciation rate of capital	Davis and Heathcote (2005)	0.0557
$\delta_s$	Depreciation rate of structures	Davis and Heathcote (2005)	0.0157
$\bar{l}$	Supply of new land	Normalization	0.023
$\phi$	Share of land in new houses	Davis and Heathcote (2007)	0.30
$\psi$	Adjustment costs to investment	JPT (2014)	2
$\beta$	Subjective discount factor	Literature	0.96
$r^*$	Foreign interest rate	Data 1967-2010	0.042
$\theta$	Loan-to-value ratio	Literature	0.35
$\gamma$	Share of non-housing good consumption	Share of construction, 5.6 %	0.87

Notes: JPT (2014) stands for Justiniano, Primiceri, and Tambalotti (2014).

## 4.2 Results

This section assesses the role of the productivity slowdown in construction relative to the rest of the economy, as well as its interaction with the low borrowing interest rate, for the evolution of US house prices and other macro variables. The secular decline in the construction productivity drives the long-run developments of house prices, while sectoral productivity shocks affect house prices over the cycle by deviating the economy from the balanced growth path. I feed the model with the estimated relative TFP shocks and I recover the optimal path of variables in a similar fashion to Davis and Heathcote (2005).

**Model fit.** Top-left panel of Figure 4 plots the series of relative TFP jointly with the estimated trend, while top-right panel reports the estimated innovations. Over the sample, relative TFP grows at a relatively constant rate and the estimated trend proxies well the long-run developments of relative productivity. This finding supports the assumption that relative TFP grows at a constant rate over the balanced growth path. The early part of the sample is featured by a sequence of positive innovations which reflects in the

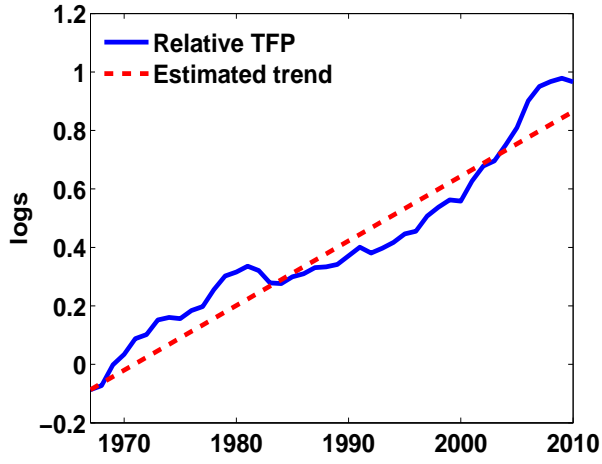
relative TFP being above trend until mid-1980's. Growth in relative TFP is weak until the mid-1990's, since then another sequence of positive innovations brings relative TFP above trend until its peak in 2007. Interestingly, over the last US recession relative TFP decelerates but does not fall below trend.

Figure 4 also plots the predictions of the model (dashed red) compared with actual data (solid blue). The model predicts the upward trend of house prices as well as trends of prices of structures and land. This finding confirms and complements results of previous literature. Davis and Heathcote (2005) and Iacoviello and Neri (2010) show that differences in sectoral productivities may explain long-run trends in US house prices. Here I emphasize that sectoral productivities, coupled with the low interest rate, account for part of the surges in house prices, land prices and residential investment over the early 2000's. Over the period 1995-2006, the price of land grew faster than price of structures, and the model captures this feature of the data. Moro and Nuño (2012) document that construction prices closely follow house prices in the US over the period 1977-1997, while prices decouple over the period 1997-2007. Here such decoupling is explained by the rapid increase in the price of land.

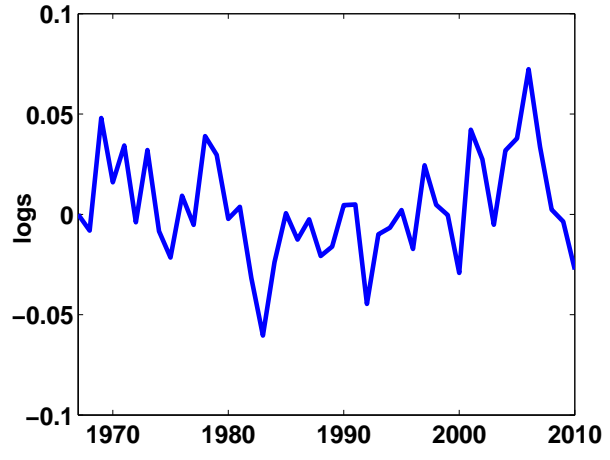
The model understates the fall in residential investment over the last recession, and consequently it generates too small busts in prices of land and houses. Although relative TFP slows down in 2007, the estimated innovations do not fall enough to trigger a bust of the magnitude as in the data. Hence movements in sectoral productivities can account for part of the recent boom in house prices but not for the subsequent bust. This result goes in line with Jermann and Quadrini (2012) and Gilchrist and Zakrajšek (2012), which show that the triggering source of the recent crisis can be identified in a large negative financial shock which has led to a credit crunch and sharp falls in economic activity and house prices. On the contrary, the price of structures is relatively stable in the data as in the model, this suggests that construction prices are mainly driven by developments in sectoral productivities.

**Productivity slowdown in construction and low borrowing rate.** A productivity slowdown in construction, by increasing house prices, increases the value of real estate and

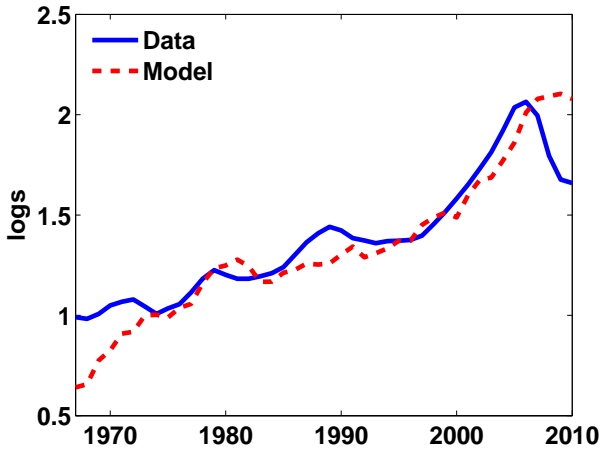
Figure 4: Estimated Relative TFP and Model Predictions



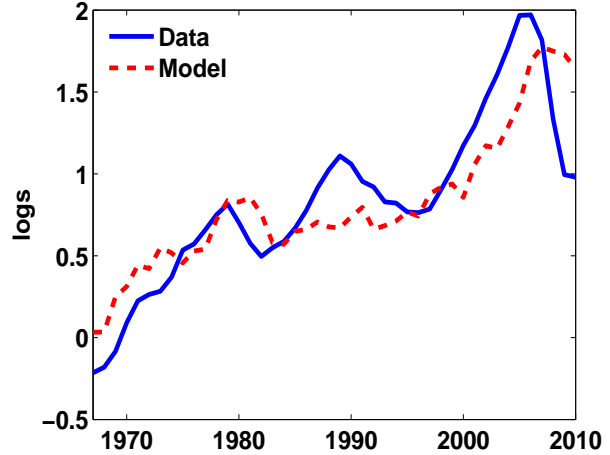
(a) Relative TFP and estimated trend



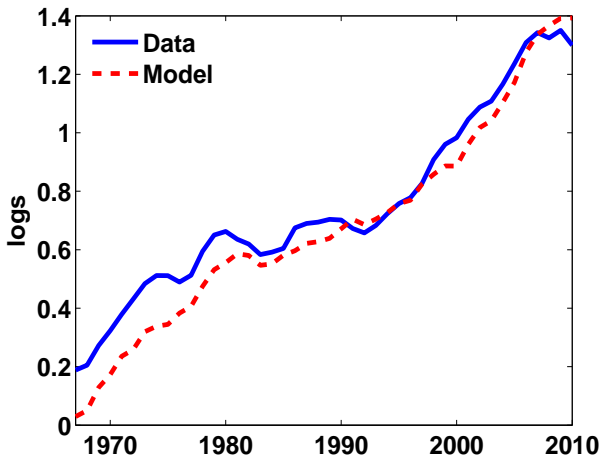
(b) Estimated relative TFP innovations



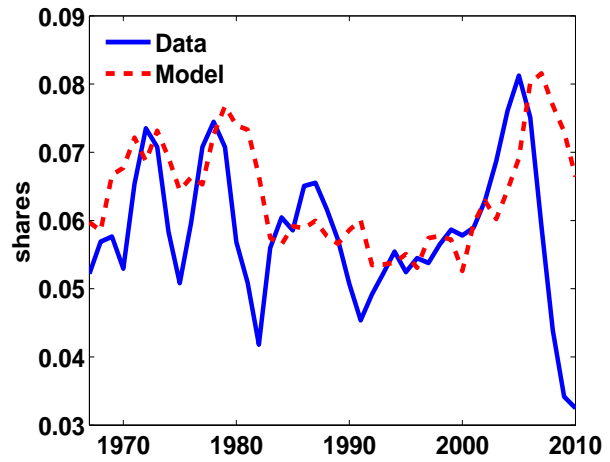
(c) House price



(d) Land price



(e) Structures price



(f) Residential investment over GDP

thus relaxes the collateral constraint. If the interest rate is sufficiently low, households find optimal to accumulate foreign debt and consequently the current account balance worsens. Capital inflows lead to a surge in residential investment, the demand for land increases, the price of land increases so eventually house prices rise further.

To quantify the interaction between the productivity slowdown in construction and a low interest rate, I compare the predictions of the model with those of an alternative closed economy in which international trade of bonds is not allowed. I focus on predictions over the period 1995-2006 which fully encloses the recent housing boom.<sup>28</sup> I also disentangle the distinct roles of secular and cyclical components of the productivity slowdown by comparing the deterministic and stochastic environments of the closed economy model. This additional exercise helps in understanding what fraction of the recent increase in house prices is attributable to the long-run decline in construction productivity.

Table 3 reports the percent changes of house prices and other macro variables from data and three versions of the model: (i) *Productivity Slowdown - Trend only* is a closed economy which features just a long-run (deterministic) change in sectoral productivities as driving factor; (ii) *Productivity Slowdown - Trend and Shocks* also includes the transitory (stochastic) component of relative productivity; (iii) *Productivity Slowdown & Low Interest Rate* is an open economy with foreign borrowing at a low interest rate which is subject to both trend and transitory changes in relative productivity. I emphasize two findings. First, the productivity slowdown in construction accounts for a substantial part of the recent increase in house prices: about 48 percent of the observed increase is due to the secular trend, nearly 30 percent is due to its stochastic component, and about 15 percent is due to the interaction with the low borrowing rate. Second, the interaction with the low borrowing rate does not just amplify the role of sectoral productivities on house prices but also allows for explaining the increase in residential investment (about 104 percent), and captures the rapid increase in the price of land (about 92 percent), which is markedly higher than the increase in the price of structures (about 53 percent). It also generates about 46 percent of the worsening of the US current account. Conversely, a closed economy version of the model predicts a counterfactual fall in residential

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<sup>28</sup>Moreover, Bernanke (2005) identifies the mid-'1990s as the starting period of the global savings glut.

investment, predicts roughly similar increases in the prices of structures and land of about 50 percent, and naturally it cannot provide predictions about movements in the current account.<sup>29</sup>

Table 3: Data and Model Predictions over 1995-2006

Percent changes over 1995-2006	Data	Productivity Slowdown		Productivity Slowdown & Low Interest Rate
		<i>Trend only</i>	<i>Trend and Shocks</i>	
House price	69.23	33.04 (47.72)	52.70 (76.12)	63.84 (92.21)
Structures price	55.03	31.97 (58.09)	53.09 (96.48)	51.69 (93.94)
Land price	120.42	35.55 (29.52)	51.79 (43.01)	92.18 (76.55)
Residential investment over GDP	35.95	0 (0)	-4.84 (-13.46)	37.55 (104.45)
Current account over GDP	-143.78	- -	- -	-65.85 (45.80)

*Notes:* figures in parentheses denote changes in the model over changes in the data, in percentages. *Productivity Slowdown* refers to a closed economy without foreign borrowing, where *Trend only* refers to the case in which the economy is subject to the trend (deterministic) change in relative productivity between construction and the rest of the economy, while *Trend plus Shocks* refers to the case in which the economy is also subject to transitory shocks in relative productivity. *Productivity Slowdown & Low Interest Rate* refers to an economy which is subject to both trend and shocks to relative productivity, and foreign borrowing is allowed.

The interaction between productivity slowdown in construction and the low borrowing rate also helps in explaining the volatility of house prices in the data. Top panel of Figure 12 in Appendix plots the relative contribution of land and structures in house prices. Over the full sample, land accounts for about 34 percent of house prices, which is close to estimates in Davis and Heathcote (2007). Further, bottom panel plots the log-differences of house prices, structure prices and land prices. Land prices are the most volatile, followed by house prices and structures prices. Table 4 reports the standard deviation of house prices, as well as standard deviations of prices of structures and land scaled by the standard deviation of house prices, computed from data and model with and without low

<sup>29</sup>The closed economy model still explains the increase in price of structures. This result is consistent with Moro and Nuño (2012), which document that TFP differences between construction and the general economy can accurately account for the evolution of US construction prices over the period 1977-2007.

borrowing interest rate.<sup>30</sup> The model which includes the interaction with the low interest rate captures the fact that the volatility of the price of land is about twice the volatility of the price of houses, and the volatility of the price of structures is about half the volatility of the housing price. Conversely, the closed economy version of the model predicts that prices of houses, structures and land are roughly equally volatile.

Table 4: Volatility of House, Structures and Land Prices: Data and Model

	$\sigma$ (House price)	$\frac{\sigma(\text{Structures price})}{\sigma(\text{House price})}$	$\frac{\sigma(\text{Land price})}{\sigma(\text{House price})}$
<i>- Using Log-Differences</i>			
Data	0.06	0.60	2.36
Productivity Slowdown	0.03	0.97	1.18
Productivity Slowdown & Low Interest Rate	0.05	0.59	1.99
<i>- Using Hodrick-Prescott Filter</i>			
Data	0.03	0.67	2.19
Productivity Slowdown	0.02	0.93	1.20
Productivity Slowdown & Low Interest Rate	0.03	0.56	2.04

*Notes:* *Productivity Slowdown* refers to a closed economy with no foreign borrowing, in which trend and shocks to relative productivity are present. *Productivity Slowdown & Low Interest Rate* refers to an economy in which trend and shocks to relative productivity are present, and foreign borrowing is allowed. The smoothing parameter of the Hodrick-Prescott filter is  $\lambda = 1600 * (1/4)^4 = 6.25$  following Ravn and Uhlig (2002) and Hodrick and Prescott (1997). Sample: 1967-2010.

To summarize, the interaction of a productivity slowdown in construction and a low borrowing interest rate explains part of the surges in prices of land and houses of the early 2000's, and it accounts for a number of features of the US housing cycle. First, it explains why house prices and residential investment are positively correlated. This feature of the data has been traditionally associated to shocks from the housing demand, here it is due to changes in sectoral technologies. Conversely, a closed economy version of the model which resembles the frameworks of Davis and Heathcote (2005) and Iacoviello and Neri (2010), predicts that sectoral technology shocks generate a counterfactual negative correlation between housing prices and investment. Second, this interaction accounts for the fact that the bulk of the volatility in house prices is due to fluctuations in the price of

<sup>30</sup>Series are either in log-differences or Hodrick-Prescott filtered using a smoothing parameter equal to  $\lambda = 1600 * (1/4)^4 = 6.25$  following Ravn and Uhlig (2002) and Hodrick and Prescott (1997).



land as documented in Davis and Heathcote (2007). And third, this interaction generates a negative correlation between house prices and current account. Justiniano, Primiceri, and Tambalotti (2014) highlight the importance of a global savings glut and attribute between one-fourth and one-third of the recent housing boom to the imbalances vis-a-vis the rest of the world. Here surges in house prices and capital inflows are the endogenous outcome of the interaction between a *domestic* factor (sectoral technology shocks) and a low borrowing interest rate.

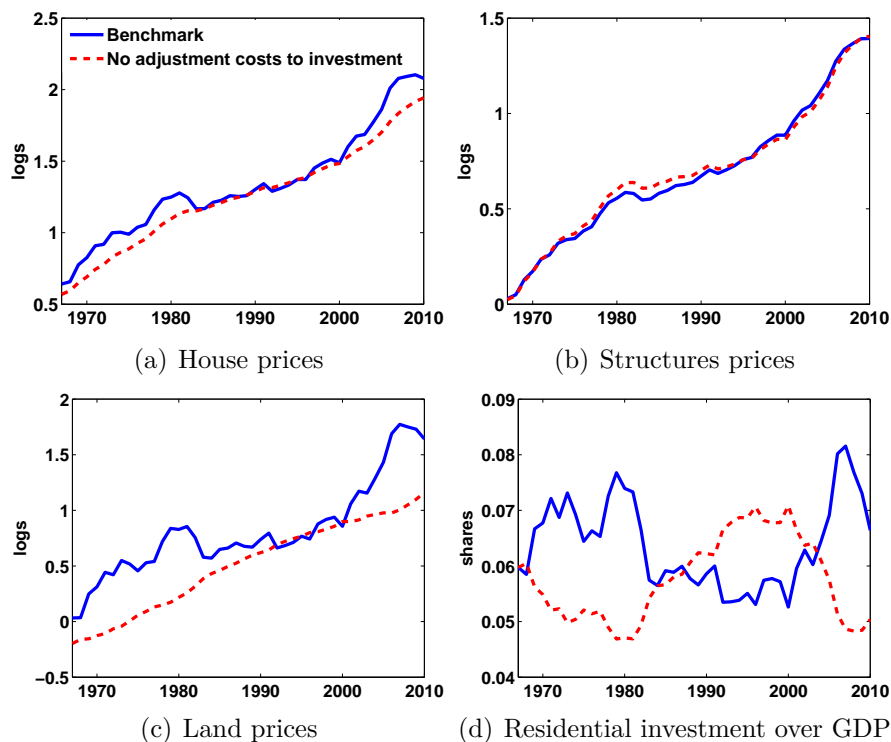
### 4.3 Robustness and Extensions

**Different simulation periods.** The definition of the sample period for simulating the model could crucially affect the results of the analysis: the estimated trend and cyclical components of relative TFP can vary with the sample period. By sequentially varying the initial year ranging from 1960 to 1975, I estimate trend and shocks in relative TFP and simulate the model. Table 8 in Appendix reports the percent changes over the period 1995-2006 for several macro variables using actual and model-simulated data for different sample periods. Last row reports the average changes across models. Column (c) refers to the economy with productivity slowdown in construction and low borrowing rate: the model explains about 95 percent of the recent surge in house prices, about 96 percent of the increase in structures prices and about 80 percent of the increase in land prices. It explains more than the actual change in residential investment (about 112 percent), and about 45 percent of the worsening of the current account. The success of the model relies on the interaction between productivity slowdown in construction and the low interest rate. The closed economy stochastic version of the model in column (b) predicts a counterfactual decrease of residential investment, and it generates an increase in the price of land which is too small and similar to the increase in the price of structures (roughly 50 percent). Results of the closed economy deterministic version of the model in column (a) confirm that the secular trend in relative productivities accounts for nearly half of the recent increase in housing price.

**The role of adjustment costs to investment.** What is the role of adjustment costs

to investment in capital? Figure 5 shows the predictions of the benchmark model (solid blue line) and the model without adjustment costs to investment (dashed red line). Despite adjustment costs have no role over the long-run, they are key to match the cyclical features of US data. The model without adjustment costs fails to match the behavior of residential investment, misses the early 2000's boom of the price of land, while captures developments in the price of structures as in the model with adjustment costs. As a consequence, the model without adjustment costs substantially understates the recent increase in house prices. The intuition is that a productivity slowdown in construction leads to an inflow of capitals which, in absence of adjustment costs, increase the share of non-residential investment in GDP at the expenses of the share of residential investment. If instead is costly to abruptly change capital, higher capital inflows lead to higher share of nonresidential investment in GDP as in the data.

Figure 5: Predictions of the Model without Adjustment Costs to Investment



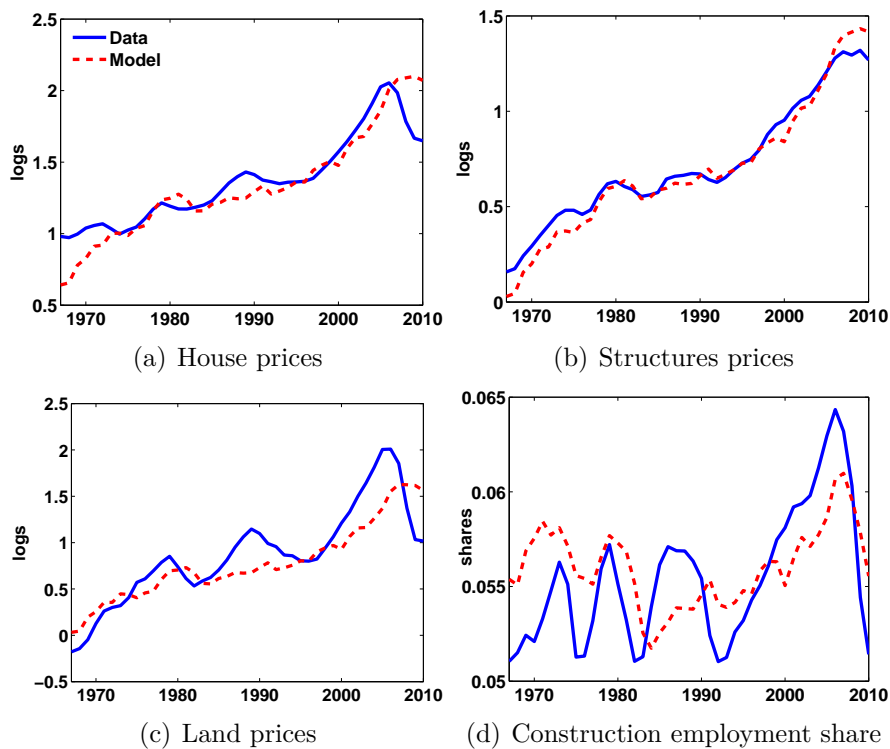
**Frictions to sectoral labor reallocation.** The benchmark model assumes that labor reallocation across sectors is frictionless. Here this assumption is relaxed by postulating

that the representative household decides the fraction of her labor endowment supplied to the construction sector,  $e_{st}$ , subject to some adjustment costs expressed in utils  $S(e_{st} - e_{st-1})$ , where the  $S$  function is parametrized as

$$S(e_{st} - e_{st-1}) = \frac{\omega}{2} (e_{st} - e_{st-1})^2 \quad (47)$$

so that over the deterministic balanced growth path it satisfies  $S = S' = 0$  and  $S'' > 0$ . This adjustment cost function is used for example in Meza and Urrutia (2011), and it captures as a reduced form the potential loss in sector-specific skills of workers which switch sector. The parameter  $\omega > 0$  measures the extent to which it is costly to switch sector and determines the persistence of the series of employment in construction. Such parameter is calibrated to match the first order serial correlation of the share of construction employment in the data, which averages 0.87, so that  $\omega = 6.015$ . The predictions of the model with frictions in sectoral reallocation are in Figure 6. The model fairly reproduces fluctuations in the share of construction employment in the data, and the qualitative implications of the model are unchanged.

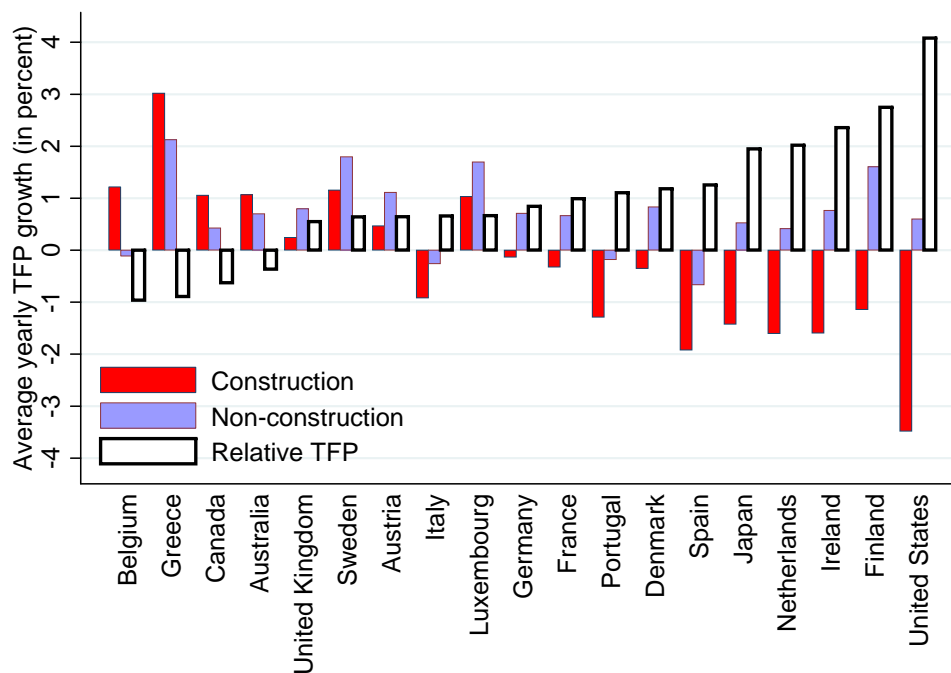
Figure 6: Predictions of the Model with Frictions in Sectoral Reallocation of Labor



## 5 International Evidence

Besides the United States, productivity slowdowns in construction have occurred in other economies. Figure 5 reports the average percent changes of TFP in construction, rest of the economy, and in relative TFP. Over the period 1995-2006, construction tends to be a relatively stagnant sector in most of the countries, and the US productivity slowdown dominates in magnitude compared to the other economies.

Figure 7: Average Growth Rates of Sectoral Productivities Across Countries, 1995-2006



Notes: *Relative TFP* refers to the average yearly growth of the ratio of TFP in non-construction over TFP in construction.

**Panel VAR evidence.** I exploit the cross-country variation in 19 OECD economies including the United States to study the empirical relevance of my proposed mechanism.<sup>31</sup> To tackle reverse causality problems I impose structural sign restrictions in a Panel VAR model. This allows me to exploit cross-sectional variation to identify relative productivity shocks even in the presence of a relatively short time series dimension, which is the period

<sup>31</sup>The economies under study are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom and United States.

1995-2007.<sup>32</sup> Panel VARs have the same structure as VAR models, in the sense that all variables are assumed to be endogenous and interdependent, but a cross sectional dimension is added to the representation.<sup>33</sup> Let

$$y_{it} = \Delta \left[ \ln Z_{it} \quad \ln p_{s,it} \quad \ln p_{l,it} \quad \ln p_{h,it} \quad \frac{CA_{it}}{GDP_{it}} \quad \ln \frac{I_{h,it}}{GDP_{it}} \right]$$

denote the vector of  $G = 6$  stationary variables for each country  $i = 1 \dots N$  and year  $t = 1 \dots T$ . Here  $Z$  denotes the ratio of non-construction TFP over construction TFP: I construct series for sectoral TFPs using a combined database which includes EU KLEMS and World Input Output Socio Economic Accounts data (see Timmer, Erumban, Gouma, Los, Temurshoev, de Vries, and Arto (2012));  $p_s$  is the price of construction deflated by the price of value added in total economy;  $p_l$  is the price of land deflated by the consumer price index;  $p_h$  is the real housing price directly obtained from the BIS Residential Property Price database described in Mack and Martínez-García (2011), and from data in Cesa-Bianchi (2013);  $\frac{CA}{GDP}$  is the current account balance over GDP obtained from Lane and Milesi-Ferretti (2007);  $\frac{I_h}{GDP}$  is the fraction of residential investment in GDP obtained from OECD. Details on data sources can be found in Section E in Appendix.  $\Delta$  is the first difference operator, which applies to all variables in the vector.

Data are annual and cover the period 1995-2007 so that  $T = 13$ . The panel VAR is

$$y_{it} = \alpha + \tau t + B(L)y_{it-1} + u_{it} \quad \forall i, t \quad (48)$$

where  $\alpha$  is a  $G \times 1$  vector of variable-specific constant,  $\tau$  are variable-specific year dummies which account for aggregate global shocks as well as for cross-country spill-overs, and  $B(L)$  is a polynomial in the lag operator. I specify a polynomial of degree zero in the lag operator  $L$ , so that the model is a VAR(1).  $u_{it}$  is a  $G \times 1$  vector of reduced form country-specific Wold innovations, with variance  $\Sigma = E(u_{it}u'_{it})$ .<sup>34</sup> Reduced form shocks

<sup>32</sup>The sample period includes most of the recent housing booms observed across countries. André (2010) document since the mid-1990's a generalized increase in real house prices across countries and a consequent bust around 2006. This fact is also documented in Claessens, Kose, and Terrones (2010) and Cesa-Bianchi (2013).

<sup>33</sup>Panel VARs have recently been used by Canova and Pappa (2007) and Calza, Monacelli, and Stracca (2012), see Canova and Ciccarelli (2013) for a survey.

<sup>34</sup>In principle this variance could vary across time and countries. Here I focus on estimating the average effect of relative TFP across time and countries.

are a linear combination of structural shocks  $\epsilon_{it}$  so that

$$V\epsilon_{it} = u_{it}$$

I normalize structural shocks so that they have unit variance,  $I = E(\epsilon_{it}\epsilon'_{it})$ . This implies the restriction that  $VV' = \Sigma$ . After purging the vector of  $y_{it}$  from trends as well as from aggregate shocks and/or spill-overs across countries obtain

$$\tilde{y}_{it} \equiv y_{it} - \alpha - \tau t = [I - B(L)]^{-1} V\epsilon_{it}$$

which fully characterize the impulse responses of the detrended variables  $\tilde{y}_{it}$  to structural shocks  $\epsilon_{it}$ . I estimate the model by pooled OLS, and I am interested in identifying the specific column of  $V$  which characterizes the impact effects of an unexpected change in the level of relative productivity in construction. I use sign restrictions to identify the effects of this relative TFP shock: in particular I require that a fall in relative productivity of construction increases the price of construction on impact and in the following two years. This amounts to impose a positive sign restriction between the impulse responses of the price level of construction and of relative TFP, where the restriction is imposed on the levels of the variables. The sign restriction is imposed not only on impact but also in the two following years to take into account that prices can adjust with some lag. Conversely, I am completely agnostic about the responses of prices of land and houses, as well as of residential investment and current account. The implementation of the sign restriction is based on the algorithm of Rubio-Ramírez, Waggoner, and Zha (2010). The results are based on 500 draws from the posterior distribution of the reduced form parameters  $B(L)$  and  $\Sigma$  with 2000 rotations each, similarly to Kilian and Murphy (2012).<sup>35</sup>

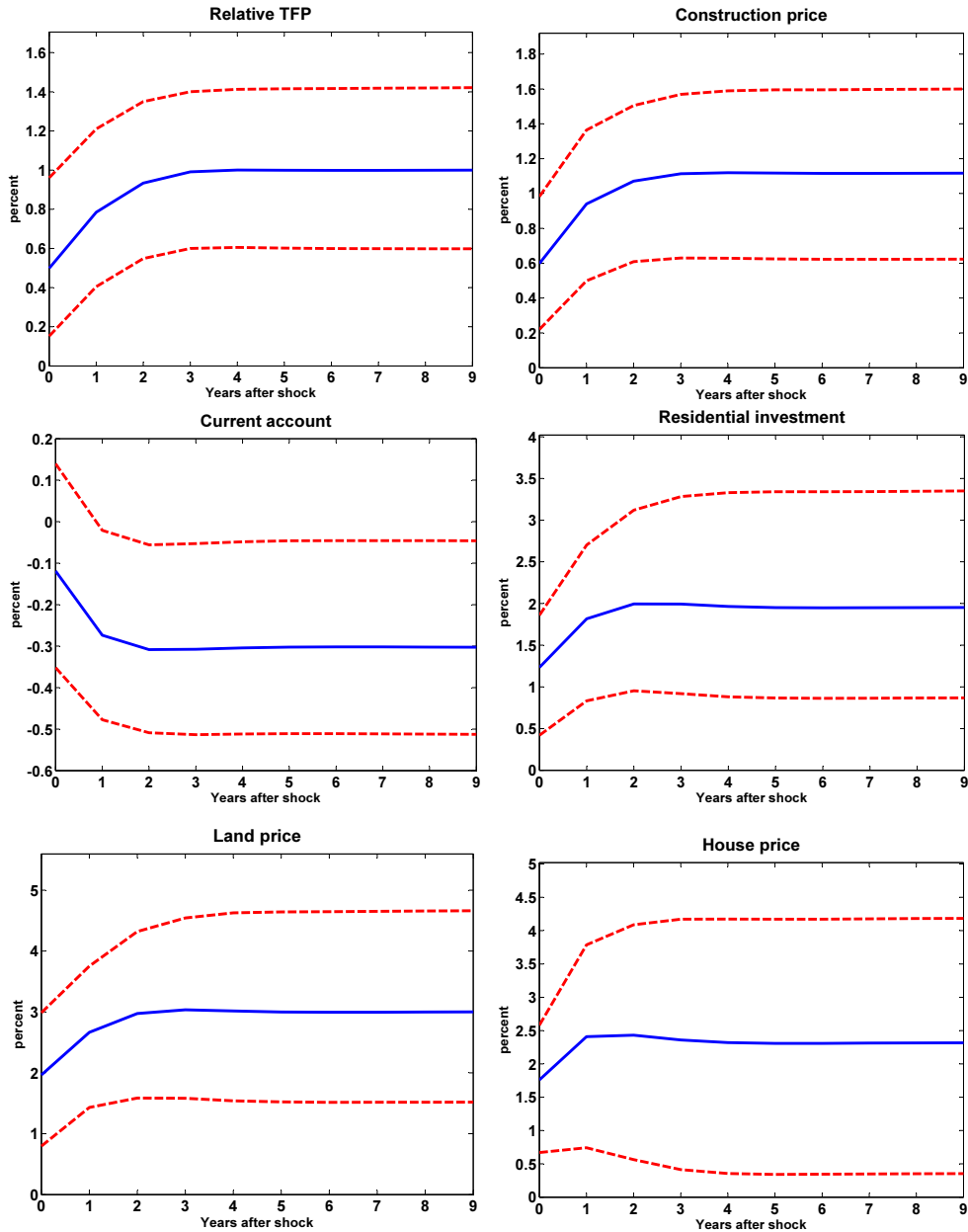
The impulse responses to a relative TFP shock are plotted in Figure 8. As common in the literature since Sims and Zha (1999) I plot 68% confidence intervals (red dashed lines), and responses are on impact and in the following nine years after the shock. The long-run response of relative TFP is normalized to 1 percent. An increase of 1 percent in non-construction productivity relative to productivity in construction leads to a 1.1 percent increase in the price of construction. The current account deteriorates, residential

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<sup>35</sup>I thank Fabio Canova and Juan Rubio-Ramírez for making their codes available to me.

investment increases by nearly 2 percent, the price of land increases by about 3 percent, and housing price rises by about 2.4 percent. Hence impulse responses have the correct sign, and this is evidence in favor of my mechanism.

Figure 8: Estimated Impulse Responses to a Relative TFP Shock



*Notes:* solid lines represent the estimated responses and dashed lines represent the 68 % probability bands. Results are based on 500 draws from the posterior distribution of the reduced form parameters and variance covariance with 2000 rotations each.

**Cross-country quantitative analysis.** (*IN PROGRESS*) As for the United States, I calibrate the model for each of the other 18 economies under study to understand the role of productivity slowdowns for the recent country-specific developments of house prices. Importantly, the proposed mechanism is designed to explain increases in house prices in economies which satisfy two features in the data: (*i*) a slowdown in relative productivity of construction; (*ii*) being a net debtor with respect to the rest of the world. Nonetheless, I include in the sample countries that did not experience a productivity slowdown in construction relative to the rest of the economy (namely Australia, Belgium, Canada and Greece), for two reasons: (*i*) to check that for these countries the model *correctly* fails to predict changes in house prices; (*ii*) to exploit cross-country variation for identifying which could be the causing factors of productivity slowdowns in construction. Following the same reasoning I also include creditor countries in the sample.

I feed the model calibrated for each economy separately with estimated country-specific series of sectoral TFP shocks, and recover the model-implied series of house prices which I compare with actual data. The first observation available is 1995 for the majority of countries and ending dates range in between 2007 and 2012. In order to better estimate trend and cyclical components of relative TFP I use all information available so that the panel of data is unbalanced.

Regarding the calibration, some parameters of the model are calibrated to target country-specific data. In particular the country-specific parameters are the sectoral capital shares, the share of non-housing good consumption, which is set to target average share of employment in construction, and the interest rate at which countries can borrow from the rest of the world, which is set to target average real government bond yields taken from OECD and EUROSTAT. Due to data limitations across countries, the rest of the parameters are fixed to the values employed in the US calibration. This is a key limitation of the analysis, as it is reasonable to think that other parameters such as the share of land in production of new houses  $\phi$  can vary across countries. Tackling this issue is in the research agenda. Details about calibration and data sources can be found in Table 9 in Appendix.

Table 5 reports main statistics of the cross-country calibration. I emphasize three



results: (i) construction is a relatively stagnant sector: on average, the growth in construction is about 0.9 percent lower than in the rest of the economy; (ii) construction is a relatively labor-intensive sector: the average capital share in construction across sectors is about 21 percent, while it is about 34 percent in the rest of the economy; (iii) countries which experience strong productivity slowdowns tend to feature a particularly labor-intensive construction sector: the cross-country correlation between estimated growth of relative TFP and capital share in construction averages minus 54 percent, Figure 13 in Appendix plots this relationship.<sup>36</sup>

Table 5: Relative TFP Growth and Country-Specific Characteristics

Parameter	Average across countries (in %)	Correlation with relative TFP growth
Relative TFP growth	0.90	1
Capital share in construction	21.04	-0.54
Capital share in non-construction	33.82	0.07
Real borrowing rate	3.34	-0.04
Non-housing good share in consumption	73.49	0.93

Despite the model is silent about the skill composition of labor across sectors, it is interesting to notice that construction is also relatively less intensive in high-skilled labor. Figure 14 in Appendix reports that the share of labor compensation which goes to high-skilled labor in construction is systematically lower than the average in the economy for all countries under study. On average, the share of high-skilled labor compensation in construction is about 13 percent, while it averages 33 percent across all industries. Already Huang, Chapman, and Butry (2009) have documented that the US construction

<sup>36</sup>Regarding the other calibrated parameters, there is no clear evidence that capital share in non-construction correlates with growth of relative TFP. A similar result applies for the real borrowing rate. On the contrary, the parameter governing the share of non-housing good consumption strongly positively correlates with relative TFP growth (about 93 percent). Such parameter is calibrated by targeting the average share of construction employment in the economy and the calibration requires solving the model over the deterministic balanced growth path. Since the solution depends on the estimated growth of relative TFP, this explains such strong correlation.

is plagued by a shortage of skilled-labor, and Allen (1985) argues that the US productivity slowdown in construction is due to a gradual shift towards construction projects which are low intensive in skilled labor. Here the evidence suggests that the shortage of skilled labor is a common feature across advanced economies, and such phenomenon may explain why construction is a relatively stagnant sector.

## 6 Conclusions

In the United States, productivity in construction experienced a downward trend relative to other industries which started around the end of the 1960's and still persists. In this paper I ask the question of whether this productivity slowdown in construction can explain the recent developments of house prices in the US. The answer to this question is yes *if* the interest rate at which the US economy has borrowed from the rest of the world is low. Since relative prices are given by relative productivities, a productivity slowdown in construction increases house prices and also relaxes the collateral constraint. If the borrowing interest rate is sufficiently low, households accumulate foreign debt and these capital inflows lead to surges in residential investment, land prices, and house prices.

I calibrate the model to match the US evidence. The productivity slowdown captures the long-term trend in house prices over the 1970's-2000's, while its combination with the low borrowing interest rate is crucial to account for the surges in house prices, land prices, and residential investment of the early 2000's. This interaction generates a number of key features of the US housing cycle and current account: (*i*) the positive correlation between housing prices and residential investment; (*ii*) land prices are twice as volatile as house prices; (*iii*) part of the worsening of the current account. Without this interaction, the productivity slowdown in construction cannot explain all these facts jointly.

This paper also documents that over the last decades productivity slowdowns in construction have occurred in several other economies around the world. Using a Panel VAR with sign restrictions I also show that this mechanism can be important to explain the dynamics of house prices across OECD economies. To further shed light on the role of productivity slowdowns in construction, I also exploit OECD cross-country data to

calibrate the model for each economy under study. Preliminary findings show that construction is on average a relatively labor-intensive sector, and countries with higher labor share in construction feature stronger productivity slowdowns. Further research on the international implications of this mechanism is in the agenda.

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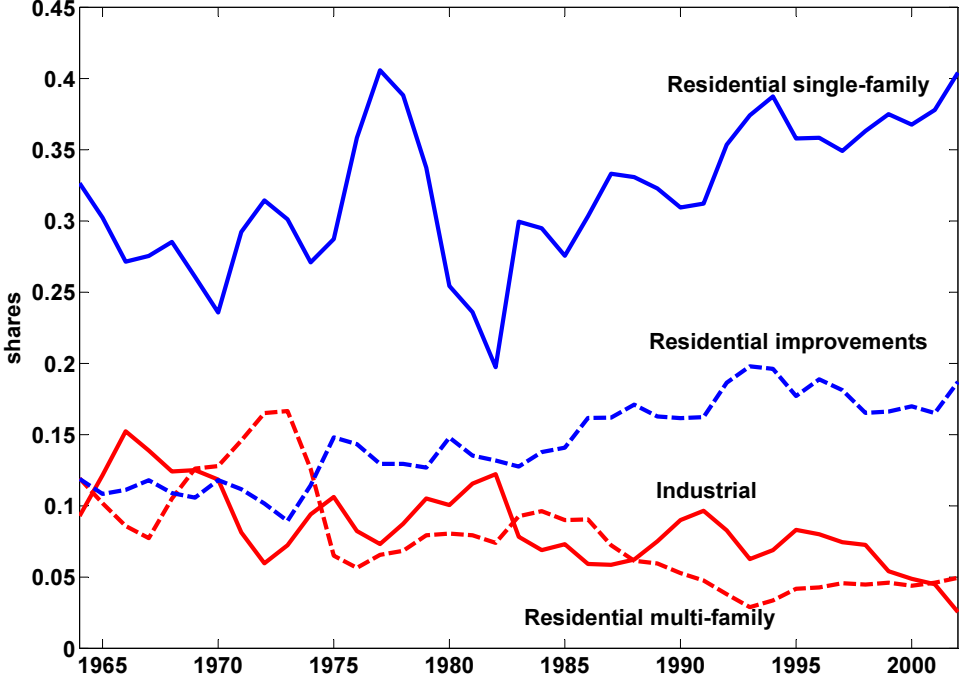
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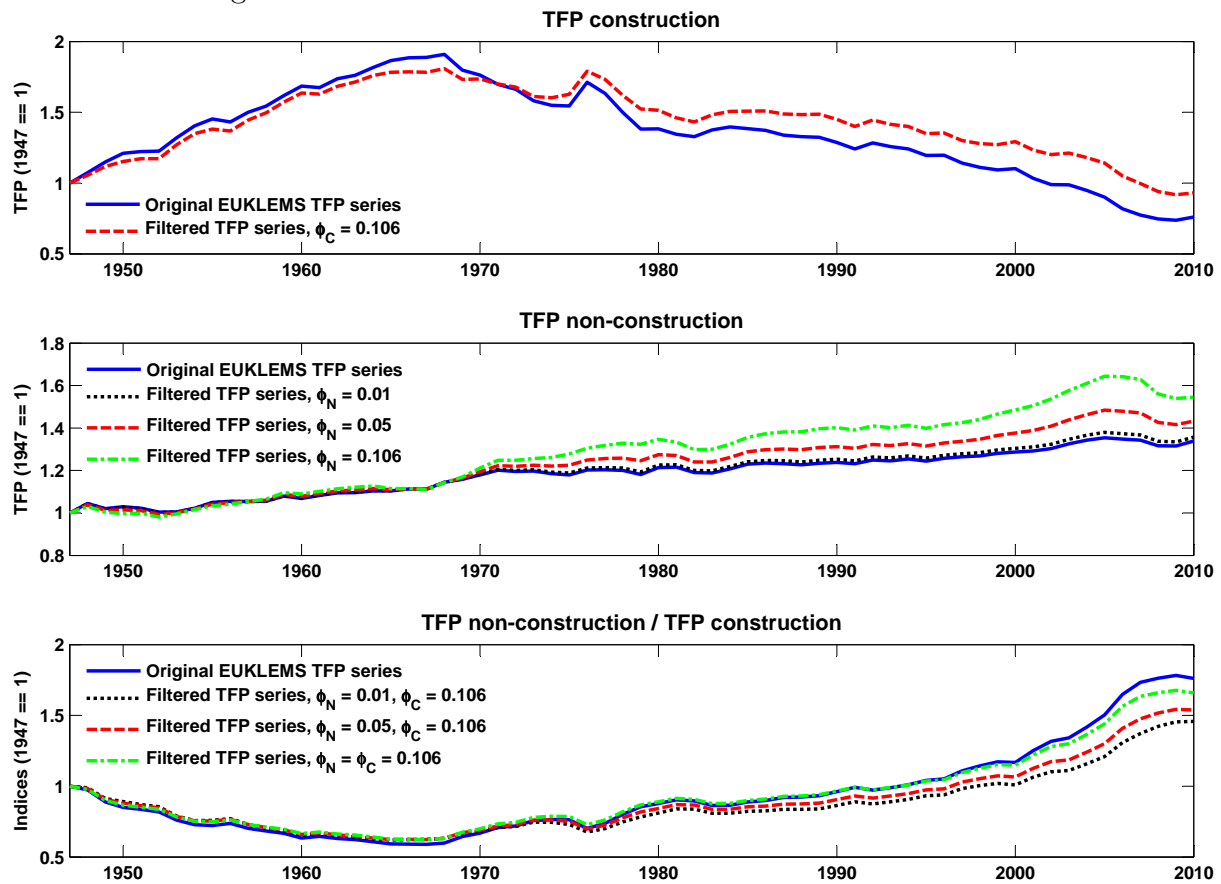
# A Figures and Tables

Figure 9: Shares in Value of Construction Put in Place



Notes: sectoral values over *Private construction* value, constant dollars, Census Bureau.

Figure 10: EU KLEMS and Land-Price Filtered TFP Series



Notes:  $\phi_C$  and  $\phi_N$  respectively denote shares of land in construction and non-construction. See Section C in Appendix for details.

Figure 11: Construction TFP: Original and Outlier-Treated Series

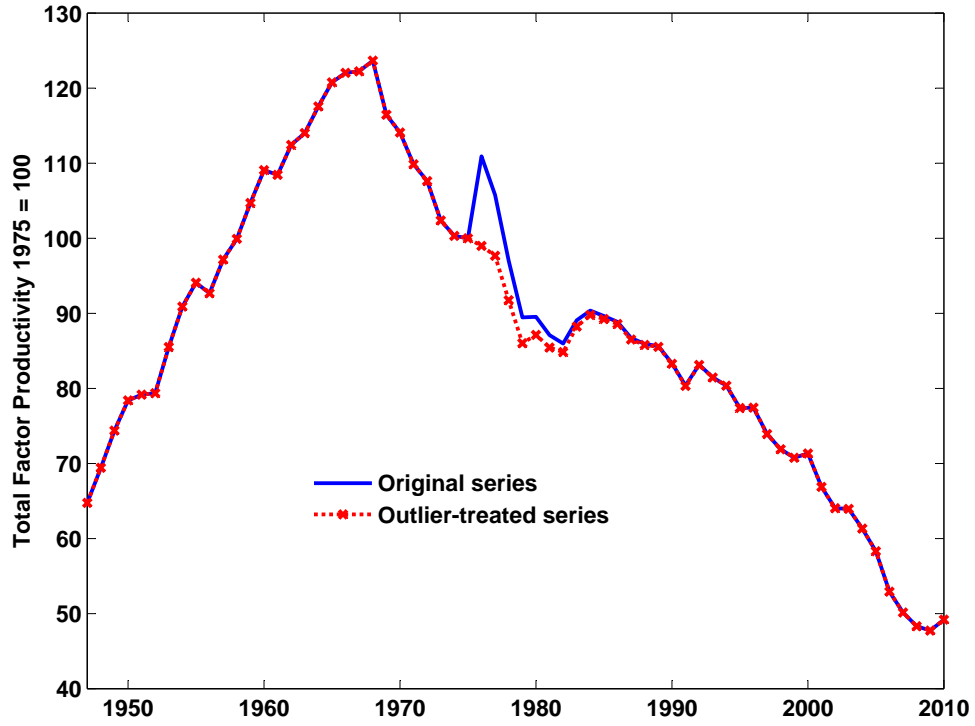
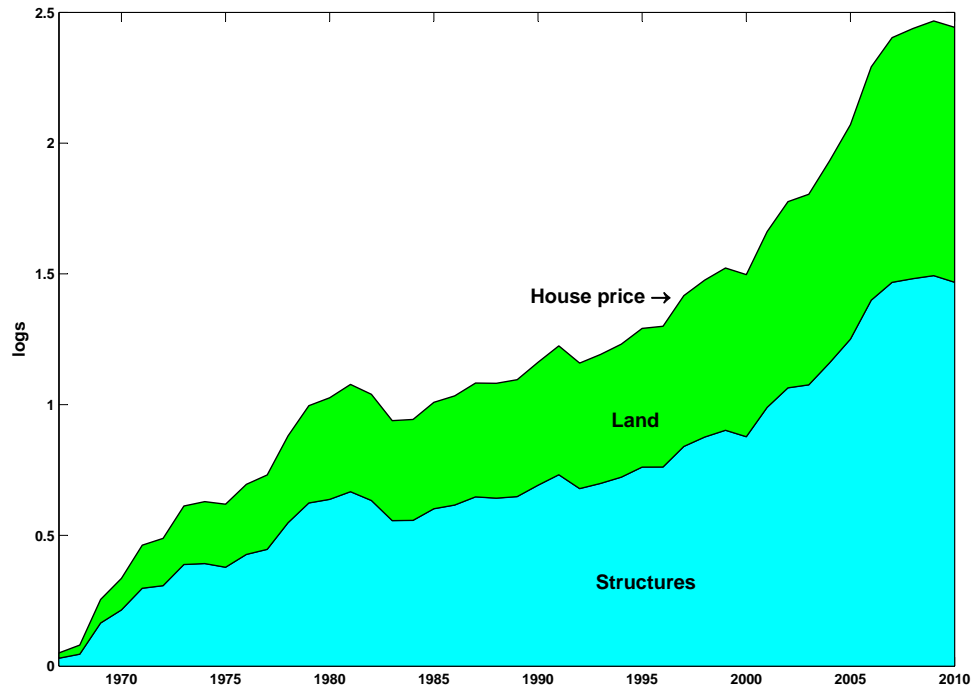
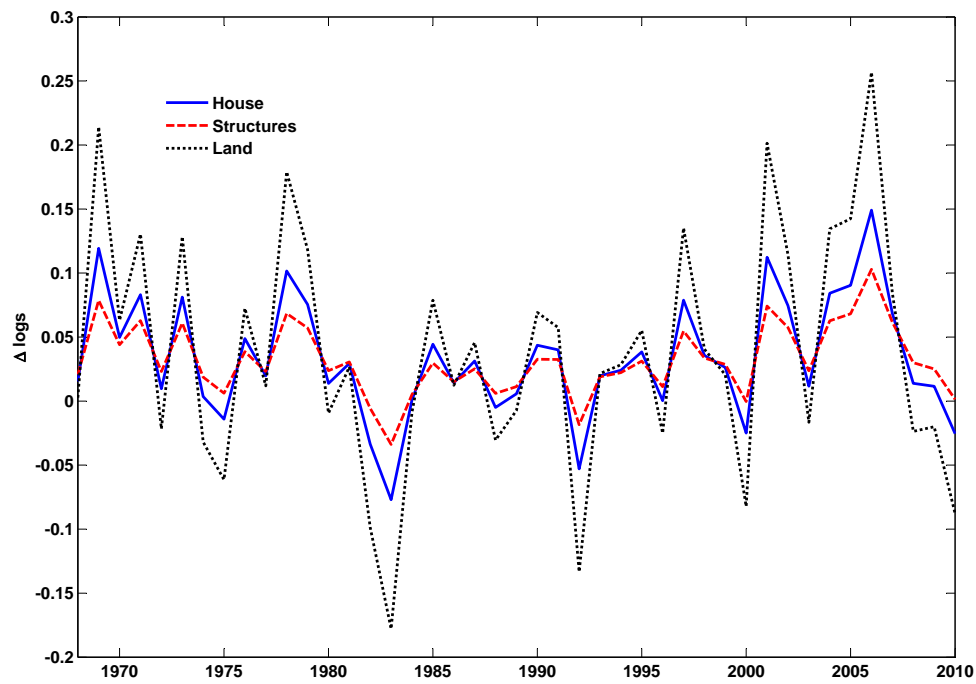


Figure 12: Contribution of Land and Structures in House Prices



(a) House prices



(b) Log-differenced prices

Figure 13: Relative TFP Growth and Capital Share in Construction

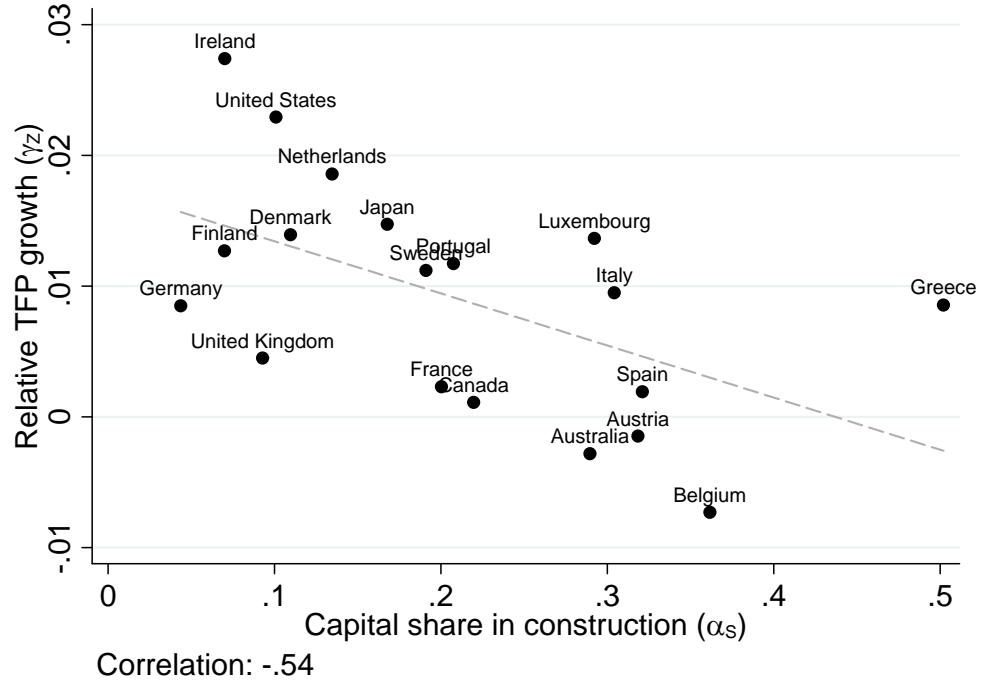
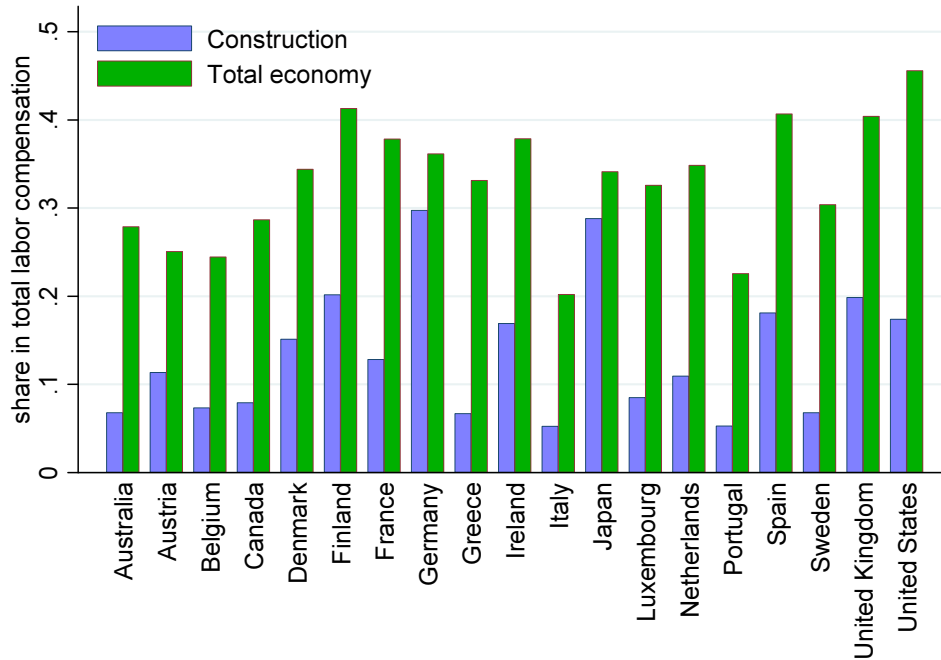


Figure 14: Compensation of High-Skilled Labor over Total Labor Compensation



Notes: averages over 1995-2009. Data is from World Input Output Database - Socioeconomic Accounts.

Table 6: Panel Data Regressions, 2000-2011

$$\Delta House Prices_{i,t} = \beta \Delta Relative Productivity Construction_{i,t} + \gamma' X_{i,t} + \alpha_i + \delta t + \varepsilon_{i,t}$$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
$\Delta$ Relative productivity	-.647*** (.067)	-.232*** (.054)	-.346*** (.054)	-.170*** (.052)	-.320*** (.052)	-.174*** (.048)	-.314*** (.086)	-.240*** (.086)	-.310*** (.113)	-.298** (.120)	-.272*** (.097)	-.264*** (.099)
$\Delta$ Household debt			.461*** (.057)	.299*** (.056)	.399*** (.063)	.275*** (.054)			-.054 (.115)	-.240 (.150)	.016 (.097)	-.153 (.130)
$\Delta$ Land prices					.013*** (.005)	.009*** (.002)					.004 (.003)	.003 (.002)
Lagged $\Delta$ House prices							.393*** (.047)	.299*** (.048)	.449*** (.064)	.422*** (.068)	.382*** (.060)	.380*** (.060)
A-B $m(6)$ statistic (rejection probability)							0.1 (0.92)	0.63 (0.53)	0.59 (0.56)	2.77 (0.01)	-0.93 (0.36)	1.85 (0.07)
Hansen J statistic (rejection probability)							48.29 (0.01)	47.38 (0.01)	49.27 (0.21)	47.49 (0.23)	50.67 (0.68)	50.66 (0.64)
Number of instruments							60	60	60	60	60	60
Trend	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
R-squared	0.26	0.46	0.45	0.52	0.49	0.54						
Observations	561	561	561	561	561	561	459	459	459	459	459	459
Number of states	51	51	51	51	51	51	51	51	51	51	51	51

Notes: annual data (2000-2011) for 50 US States plus District of Columbia. Dependent variable is the change in real logged house prices. Regressors are the changes in logged labor productivity in construction relative to overall productivity, changes in logged real household debt per capita, and changes in logged real land prices. Columns (1)-(6): estimation with State-level fixed effects. Columns (7)-(12): Arellano-Bond (2001) two-step estimation using as instruments up to t-6 lags of dependent and regressors. Standard errors are clustered at the State level. \*\*\*, \*\*, \*, indicates significance at the 1, 5, and 10 percent level respectively.

Table 7: Panel Data Regressions, 2000-2011, using Davis and Heathcote (2007) House Price Series

$$\Delta House Prices_{i,t} = \beta \Delta Relative Productivity Construction_{i,t} + \gamma' X_{i,t} + \alpha_i + \delta t + \varepsilon_{i,t}$$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
$\Delta$ Relative productivity	-0.644*** (.072)	-0.167** (.064)	-0.309*** (.065)	-0.101 (.066)	-0.275*** (.061)	-0.106* (.060)	-0.265*** (.081)	-0.283*** (.090)	-0.361*** (.119)	-0.360*** (.123)	-0.324*** (.101)	-0.326*** (.102)
$\Delta$ Household debt			.513*** (.060)	.320*** (.056)	.430*** (.062)	.287*** (.050)			-.236* (.130)	-.352* (.186)	-.160 (.119)	-.170 (.174)
$\Delta$ Land prices					.017*** (.004)	.012*** (.001)					.007*** (.003)	.007*** (.003)
Lagged $\Delta$ House prices							.362*** (.051)	.375*** (.053)	.501*** (.068)	.511*** (.078)	.415*** (.074)	.415*** (.079)
A-B $m(6)$ statistic (rejection probability)							1.23 0.218	1.18 0.239	3.08 0.002	3.56 0	2.33 0.02	2.4 0.016
Hansen J statistic (rejection probability)							49.32 0.008	48.35 0.007	50.34 0.177	49.23 0.177	50.46 0.684	50.08 0.663
Number of instruments							60	60	60	60	60	60
Trend	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
R-squared	0.222	0.451	0.426	0.510	0.477	0.535						
Observations	561	561	561	561	561	561	459	459	459	459	459	459
Number of states	51	51	51	51	51	51	51	51	51	51	51	51

Notes: annual data (2000-2011) for 50 US States plus District of Columbia. Dependent variable is the change in real logged house prices. Regressors are the changes in logged labor productivity in construction relative to overall productivity, changes in logged real household debt per capita, and changes in logged real land prices. Columns (1)-(6): estimation with State-level fixed effects. Columns (7)-(12): Arellano-Bond (2001) two-step estimation using as instruments up to t-6 lags of dependent and regressors. Standard errors are clustered at the State level. \*\*\*, \*\*, \*, indicates significance at the 1, 5, and 10 percent level respectively.



Table 8: Predicted Percent Changes over 1995-2006 Across Different Simulation Samples

Data	House price			Structures price			Land price			Residential investment over GDP			Current account over GDP		
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
Model															
<i>Benchmark: 1967-2010</i>	33.04 (47.72)	52.70 (76.12)	63.84 (92.21)	31.97 (58.09)	53.09 (96.48)	51.69 (93.94)	35.55 (29.52)	51.79 (43.01)	92.18 (76.55)	0 (0)	-4.84 (-13.46)	37.55 (104.45)	-	-	-65.85 (45.80)
<i>Model: 1960-2010</i>	31.08 (44.90)	52.21 (75.40)	62.76 (90.65)	30.07 (54.65)	53.60 (97.41)	53.87 (97.90)	33.45 (27.77)	48.94 (40.65)	83.50 (69.34)	0 (0)	-7.95 (-22.12)	26.22 (72.91)	-	-	-52.91 (36.80)
<i>Model: 1965-2010</i>	33.13 (47.85)	53.07 (76.65)	65.43 (94.50)	32.05 (58.24)	53.62 (97.44)	52.56 (95.52)	35.65 (29.60)	51.79 (43.01)	95.45 (79.27)	0 (0)	-5.37 (-14.93)	39.78 (110.65)	-	-	-65.64 (45.65)
<i>Model: 1970-2010</i>	32.43 (46.85)	52.78 (76.24)	69.53 (100.43)	31.38 (57.02)	53.46 (97.15)	52.63 (95.64)	34.90 (28.98)	51.20 (42.52)	108.97 (90.49)	0 (0)	-5.72 (-15.92)	53.14 (147.81)	-	-	-73.17 (50.89)
<i>Model: 1975-2010</i>	33.81 (48.84)	53.89 (77.84)	67.70 (97.79)	32.71 (59.45)	54.49 (99.02)	53.58 (97.36)	36.38 (30.21)	52.51 (43.60)	100.65 (83.59)	0 (0)	-5.59 (-15.56)	43.82 (121.87)	-	-	-66.45 (46.22)
<i>Average across models</i>	32.70 (47.23)	52.93 (76.45)	65.85 (95.11)	31.64 (57.49)	53.65 (97.50)	52.87 (96.07)	35.18 (29.22)	51.25 (42.56)	96.15 (79.85)	0 (0)	-5.89 (-16.39)	40.10 (111.54)	-	-	-64.80 (45.07)

Notes: figures in parentheses denote changes in the model over changes in the data, in percentages. Model (a) refers to a closed economy without foreign borrowing which is subject to trend (deterministic) changes in relative productivity; model (b) refers to a closed economy without foreign borrowing which is subject to both trend and stochastic changes in relative productivity; model (c) refers to an economy which is subject to both trend and shocks to relative productivity, and foreign borrowing is allowed.

Table 9: Cross-Country Calibration and Data Sources

Country	IFS code	Sample	Parameters / Targets					Construction share (in %)	$r^*$	Data Sources		
			$\gamma_Z$	$\alpha_S$	$\alpha_N$	$\gamma$	$\gamma$			Sectoral data	Real government bond yield	Real House Prices
Australia	AUS	1995-2009	-0.003	0.29	0.31	0.53	8.10	0.034	WIOD	OECD	Dallas FED	
Austria	AUT	1980-2009	-0.001	0.32	0.32	0.58	7.27	0.034	EU KLEMS	OECD	Cesa-Bianchi (2013)	
Belgium	BEL	1995-2009	-0.007	0.36	0.37	0.54	5.95	0.029	EU KLEMS	OECD	Dallas FED	
Canada	CAN	1977-2008	0.001	0.22	0.42	0.65	6.90	0.041	EU KLEMS	OECD	Dallas FED	
Denmark	DNK	1995-2007	0.014	0.11	0.26	0.83	6.05	0.031	WIOD	OECD	Dallas FED	
Finland	FIN	1975-2012	0.013	0.07	0.31	0.75	7.34	0.041	EU KLEMS	OECD	Dallas FED	
France	FRA	1980-2009	0.002	0.20	0.31	0.64	6.82	0.043	EU KLEMS	OECD	Cesa-Bianchi (2013)	
Germany	DEU	1991-2009	0.008	0.04	0.33	0.78	7.24	0.032	EU KLEMS	OECD	Dallas FED	
Greece	GRC	1995-2009	0.009	0.50	0.36	0.77	7.26	0.020	WIOD	OECD	Cesa-Bianchi (2013)	
Ireland	IRL	1995-2007	0.027	0.07	0.43	0.94	10.29	0.038	WIOD	OECD	Dallas FED	
Italy	ITA	1972-2009	0.009	0.30	0.30	0.69	7.62	0.038	EU KLEMS	OECD	Dallas FED	
Japan	JPN	1973-2009	0.015	0.17	0.37	0.86	9.46	0.023	EU KLEMS	OECD	Dallas FED	
Luxembourg	LUX	1995-2009	0.014	0.29	0.33	0.82	10.63	0.019	WIOD	EUROSTAT	Dallas FED	
Netherlands	NLD	1988-2009	0.019	0.13	0.34	0.87	6.06	0.035	EU KLEMS	OECD	Dallas FED	
Portugal	PRT	1995-2008	0.012	0.21	0.27	0.79	10.44	0.020	WIOD	EUROSTAT	Dallas FED	
Spain	ESP	1980-2009	0.002	0.32	0.36	0.51	9.77	0.038	EU KLEMS	OECD	Dallas FED	
Sweden	SWE	1993-2011	0.011	0.19	0.43	0.83	5.66	0.038	WIOD	OECD	Dallas FED	
United Kingdom	GBR	1990-2011	0.004	0.09	0.31	0.70	7.02	0.038	EU KLEMS	OECD	Dallas FED	

## B Deriving the stationarized equilibrium conditions

In a balanced growth path all aggregates grow at a constant rate or are constant. For instance the real interest rate is assumed to be constant over the balanced growth path. And since production functions and preferences are of the Cobb-Douglas type, labor shares are constant too. Given that the interest rate is constant, equation (38) reads

$$p_{St} = \Phi Z_t^{\frac{1-\alpha_S}{1-\alpha_N}} r^{\frac{\alpha_S-\alpha_N}{1-\alpha_N}} \quad (49)$$

hence it has to be that the price of structures grows at the rate

$$1 + \gamma_{p_s} = (1 + \gamma_Z)^{\frac{1-\alpha_S}{1-\alpha_N}} \quad (50)$$

From the optimal demand for capital in non-construction it has to be that

$$\frac{k_{Nt}}{e_{Nt}} = \left( \frac{\alpha_N Z_t}{r} \right)^{\frac{1}{1-\alpha_N}} \quad (51)$$

hence it has to be that capital in non-construction sector grows at the following rate

$$1 + \gamma_{k_N} = (1 + \gamma_Z)^{\frac{1}{1-\alpha_N}} \quad (52)$$

hence from the optimal demand for labor in non-construction, the growth rate of wages is given by

$$1 + \gamma_w = (1 + \gamma_Z)(1 + \gamma_{k_N})^{\alpha_N} = (1 + \gamma_Z)^{\frac{1}{1-\alpha_N}} \quad (53)$$

Similarly, from the optimal demand for capital in construction,

$$\frac{k_{St}}{e_{St}} = \left( \frac{\alpha_S p_{st}}{r} \right)^{\frac{1}{1-\alpha_S}} \quad (54)$$

hence capital in the construction sector grows at the rate

$$1 + \gamma_{k_S} = (1 + \gamma_{p_s})^{\frac{1}{1-\alpha_S}} = (1 + \gamma_Z)^{\frac{1}{1-\alpha_N}} \quad (55)$$

therefore from the market clearing of capital and the law of motion of capital, aggregate capital and non-residential investment grow at the common rate

$$1 + \gamma_k = 1 + \gamma_{i_k} = (1 + \gamma_Z)^{\frac{1}{1-\alpha_N}} \quad (56)$$

From the Cobb-Douglas production functions in non-construction and construction it has to be that sectoral outputs grow at rates

$$1 + \gamma_{y_N} = (1 + \gamma_Z)(1 + \gamma_{k_N})^{\alpha_N} = (1 + \gamma_Z)^{\frac{1}{1-\alpha_N}} \quad (57)$$

and

$$1 + \gamma_{y_S} = (1 + \gamma_{k_S})^{\alpha_S} = (1 + \gamma_Z)^{\frac{\alpha_S}{1-\alpha_N}} \quad (58)$$

Then from market clearing, structures grow at rate

$$1 + \gamma_s = 1 + \gamma_{y_S} = (1 + \gamma_Z)^{\frac{\alpha_S}{1-\alpha_N}} \quad (59)$$

From equation (40) it has to be that the price of land grows at rate

$$1 + \gamma_{p_l} = (1 + \gamma_{p_s})(1 + \gamma_{y_S}) = (1 + \gamma_Z)^{\frac{1}{1-\alpha_N}} \quad (60)$$

so the rate of growth of house prices is derived from equation (33),

$$1 + \gamma_{p_h} = (1 + \gamma_{p_l})^\phi (1 + \gamma_{p_s})^{1-\phi} = (1 + \gamma_Z)^{\frac{1-\alpha_S(1-\phi)}{1-\alpha_N}} \quad (61)$$

Given that adjustment costs to investment are zero in the deterministic balanced growth path, the households' Euler equation (20) implies that the Tobin's  $q$  is constant and equal to one. Hence from the household's Euler equation for capital and consumption, obtain

$$\frac{c_{t+1}}{c_t} = \beta(1 + r - \delta_k) \quad (62)$$

which implies that non-housing consumption grows at the to-be-determined constant rate  $\gamma_c$ . Hence from the household's optimal demand of foreign debt it has to be that the tightness of the collateral constraint  $\eta$  is constant over the deterministic balanced growth path. Then from the household's optimal choice of new houses, the ratio of non-housing over housing expenditures is given by

$$\begin{aligned} \frac{c_t}{p_{ht+1}h_{t+1}} &= \frac{\gamma}{\beta(1-\gamma)} \left[ \frac{p_{ht}}{p_{ht+1}} - \beta(1-\delta_h + \theta\eta) \frac{c_t}{c_{t+1}} \right] \\ &= \frac{\gamma}{\beta(1-\gamma)} \left[ \frac{1}{1+\gamma_{p_h}} - \frac{1-\delta_h + \theta\eta}{1+\gamma_c} \right] \end{aligned}$$

and hence it is constant. So houses grow at constant rate given by

$$1 + \gamma_h = \frac{1 + \gamma_c}{1 + \gamma_{p_h}} \quad (63)$$

From the Cobb-Douglas production function of new houses and the market clearing conditions for houses, land and structures, it has to be that housing output and residential investment grow at the rate

$$1 + \gamma_{y_h} = 1 + \gamma_{i_h} = (1 + \gamma_{y_S})^{1-\phi} = (1 + \gamma_Z)^{\frac{\alpha_S(1-\phi)}{1-\alpha_N}} \quad (64)$$

Then from the law of motion of houses the following relationship holds

$$1 + \gamma_h = 1 + \gamma_{i_h} = (1 + \gamma_Z)^{\frac{\alpha_S(1-\phi)}{1-\alpha_N}} \quad (65)$$

which can be used in (63) to recover the growth of non-housing consumption

$$1 + \gamma_c = (1 + \gamma_Z)^{\frac{1}{1-\alpha_N}} \quad (66)$$

From the (binding) collateral constraint, foreign debt grows at constant rate

$$1 + \gamma_d = (1 + \gamma_{p_h})(1 + \gamma_h) = (1 + \gamma_Z)^{\frac{1}{1-\alpha_N}} \quad (67)$$

hence from the law of motion of debt, net exports grow at rate

$$1 + \gamma_x = 1 + \gamma_d = (1 + \gamma_Z)^{\frac{1}{1-\alpha_N}} \quad (68)$$

Finally the aggregate resource constraint implies that

$$1 + \gamma_y = 1 + \gamma_c = (1 + \gamma_Z)^{\frac{1}{1-\alpha_N}} \quad (69)$$

hence the ratios consumption-output, capital-output, investment-output and foreign debt over output are constant. So in the deterministic balanced growth path all variables are either constant or grow at constant variable-specific rates. Given the relationship between trending and stationary variables in (44), the stationarized equilibrium conditions over the stochastic balanced growth path read

#### 1. Optimal demand for labor in non-construction sector

$$(1 - \alpha_N) \hat{Z}_t \hat{k}_{Nt}^{\alpha_N} e_{Nt}^{-\alpha_N} = \hat{w}_t \quad (70)$$

2. Optimal demand for labor in construction sector

$$(1 - \alpha_S)\hat{p}_{st}\hat{k}_{St}^{\alpha_S}e_{St}^{-\alpha_S} = \hat{w}_t \quad (71)$$

3. Optimal demand for capital in non-construction sector

$$\alpha_N\hat{Z}_t\hat{k}_{Nt}^{\alpha_N-1}e_{Nt}^{1-\alpha_N} = r_t \quad (72)$$

4. Optimal demand for capital in construction sector

$$\alpha_S\hat{p}_{st}\hat{k}_{St}^{\alpha_S-1}e_{St}^{1-\alpha_S} = r_t \quad (73)$$

5. Optimal demand for land

$$\phi\hat{p}_{ht}l_t^{\phi-1}\hat{s}_t^{1-\phi} = \hat{p}_{lt} \quad (74)$$

6. Optimal demand for structures

$$(1 - \phi)\hat{p}_{ht}l_t^\phi\hat{s}_t^{-\phi} = \hat{p}_{st} \quad (75)$$

7. Technology in non-construction sector

$$\hat{y}_{Nt} = \hat{Z}_t\hat{k}_{Nt}^{\alpha_N}e_{Nt}^{1-\alpha_N} \quad (76)$$

8. Technology in construction sector

$$\hat{y}_{St} = \hat{k}_{St}^{\alpha_S}e_{St}^{1-\alpha_S} \quad (77)$$

9. Real estate technology

$$\hat{y}_{ht} = l_t^\phi\hat{s}_t^{1-\phi} \quad (78)$$

10. Household's Euler equation for capital

$$q_t = \frac{\beta}{1 + \gamma_c} E_t \left\{ \frac{\hat{c}_t}{\hat{c}_{t+1}} [r_{t+1} + (1 - \delta_k)q_{t+1}] \right\} \quad (79)$$

11. Household's Euler equation for nonresidential investment

$$1 = q_t \left\{ 1 - \frac{\psi}{2} \left[ (1 + \gamma_{i_k}) \left( \frac{\hat{i}_{kt}}{\hat{i}_{kt-1}} - 1 \right) \right]^2 - \psi (1 + \gamma_{i_k})^2 \frac{\hat{i}_{kt}}{\hat{i}_{kt-1}} \left( \frac{\hat{i}_{kt}}{\hat{i}_{kt-1}} - 1 \right) \right\} + \beta \psi (1 + \gamma_{i_k})^2 E_t \left[ \frac{\hat{c}_t}{\hat{c}_{t+1} (1 + \gamma_c)} q_{t+1} \frac{\hat{i}_{kt+1}}{\hat{i}_{kt}} \left( \frac{\hat{i}_{kt+1}}{\hat{i}_{kt}} - 1 \right) \right] \quad (80)$$

12. Household's Euler equation for foreign debt

$$1 - \eta_t = \frac{\beta}{1 + \gamma_c} (1 + r^*) E_t \left( \frac{\hat{c}_t}{\hat{c}_{t+1}} \right) \quad (81)$$

13. Household's Euler equation for residential investment

$$\hat{p}_{ht} = \frac{\beta}{1 + \gamma_c} \left\{ \frac{1 - \gamma}{\gamma} \frac{\hat{c}_t}{\hat{h}_{t+1}} + (1 - \delta_h) E_t \left[ (1 - \delta_h + \theta \eta_{t+1}) \frac{\hat{c}_t \hat{p}_{ht+1}}{\hat{c}_{t+1}} \right] \right\} \quad (82)$$

14. Law of motion of capital

$$(1 + \gamma_k) \hat{k}_{t+1} = (1 - \delta_k) \hat{k}_t + \left\{ 1 - \frac{\psi}{2} \left[ (1 + \gamma_{i_k}) \left( \frac{\hat{i}_{kt}}{\hat{i}_{kt-1}} - 1 \right) \right]^2 \right\} \hat{i}_{kt} \quad (83)$$

15. Law of motion of houses

$$(1 + \gamma_h) \hat{h}_{t+1} = (1 - \delta_h) \hat{h}_t + \hat{i}_{ht} \quad (84)$$

16. Law of motion of debt

$$(1 + \gamma_d) \hat{d}_{t+1} = (1 + r^*) \hat{d}_t - \hat{x}_t \quad (85)$$

17. Market clearing of non-housing good

$$\hat{c}_t + \hat{i}_{kt} + \hat{x}_t = \hat{y}_{Nt} \quad (86)$$

18. Market clearing of housing

$$\hat{i}_{ht} = \hat{y}_{ht} \quad (87)$$

19. Market clearing of structures

$$\hat{s}_t = \hat{y}_{St} \quad (88)$$

20. Market clearing of land

$$l_t = \bar{l} \quad (89)$$

21. Market clearing of capital

$$\hat{k}_{Nt} + \hat{k}_{St} = \hat{k}_t \quad (90)$$

22. Definition of aggregate output

$$\hat{y}_t = \hat{y}_{Nt} + \hat{p}_{ht}\hat{y}_{ht} \quad (91)$$

## C Dealing with land in sectoral TFP measures

Fluctuations in land prices potentially affect TFP, being land an omitted factor of production in standard approaches in measuring productivity. This section tackles this issue and derive series of sectoral productivities which net out the role of land prices using a simple theoretical framework. It is assumed that a representative firm in a given sector  $i$  produces a good using a Cobb-Douglas technology in capital, labor and land (for simplicity suppress subscript  $i$ )

$$y_t = A_t \left( k_t^\alpha e_t^{1-\alpha} \right)^{1-\phi} l_t^\phi \quad (92)$$

where  $y$  is output,  $A$  is sectoral TFP,  $k$  capital,  $e$  is labor,  $l$  is land and  $0 < \phi < 1$  is the share of land in production. The Cobb-Douglas production function in capital, labor, and land has been employed for example in Iacoviello and Neri (2010). If  $\phi = 0$  the production function boils down to the traditional Cobb-Douglas function in capital and labor, that is the theoretical backbone of EU KLEMS methodology to estimate sectoral productivities. The firm maximizes profits by choosing how much capital, labor and land to employ, taking prices as given

$$\max_{e_t, k_t, l_t} A_t \left( k_t^\alpha e_t^{1-\alpha} \right)^{1-\phi} l_t^\phi - w_t e_t - r_t k_t - p_{lt} l_t \quad (93)$$

where the produced good is assumed to be the numeraire,  $w_t$  is the wage,  $r_t$  is the rental price of capital and  $p_{lt}$  is the relative price of land. This framework postulates that the firm buys land from the household, and the supply of land is assumed to increase by an



exogenous amount of acreage which is given to the household at the beginning of each period as in Davis and Heathcote (2005).<sup>37</sup> The first order conditions of the problem are,

$$(1 - \phi)(1 - \alpha) \frac{y_t}{e_t} = w_t \quad (94)$$

$$(1 - \phi)\alpha \frac{y_t}{k_t} = r_t \quad (95)$$

$$\phi \frac{y_t}{l_t} = p_{lt} \quad (96)$$

By combining (96) and (92) obtain

$$y_t = A_t^{\frac{1}{1-\phi}} k_t^\alpha e_t^{1-\alpha} \phi^{\frac{\phi}{1-\phi}} p_{lt}^{-\frac{\phi}{1-\phi}} \quad (97)$$

which can be also written as

$$\frac{y_t}{k_t^\alpha e_t^{1-\alpha}} = A_t^{\frac{1}{1-\phi}} \phi^{\frac{\phi}{1-\phi}} p_{lt}^{-\frac{\phi}{1-\phi}} \quad (98)$$

The left-hand-side of equation (99) is the ratio of sectoral value added over the capital and labor contributions, which corresponds to the definition of sectoral TFP as measured in EU KLEMS. Denote the left-hand-side as  $B_t$  and rewrite equation (99) accordingly,

$$B_t = A_t^{\frac{1}{1-\phi}} \phi^{\frac{\phi}{1-\phi}} p_{lt}^{-\frac{\phi}{1-\phi}} \quad (99)$$

If land is absent from production ( $\phi = 0$ ), the EU KLEMS measure of productivity corresponds to the sectoral TFP level  $A_t$ . But if land enters in production ( $\phi > 0$ ), the EU KLEMS TFP measure is function of sectoral TFP and the price of land. In this case changes in price of land affect measured productivity: a rise in price implies a fall in measured sectoral productivity, where the magnitude of the fall is increasing in the share of land employed in production,  $\phi$ . For a given estimate of  $\phi$ , I can recover the TFP level  $A_t$  as

$$A_t = \phi^{-\phi} B_t^{1-\phi} p_{lt}^\phi \quad (100)$$

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<sup>37</sup>This assumption allows me to derive a simple equilibrium relationship which links sectoral TFP and price of land. Given data on land prices, it is then straightforward to estimate land-free sectoral TFPS. An alternative choice would be to assume that the firm rents land from the household and derive an equilibrium relationship which links sectoral TFP and rental price of land. In that case the difficulty is that there is no data on rental price of land, which has then to be estimated using the household's Euler equation for land conditioning on the value of the subjective discount factor of the household.

In practice I evaluate equation (100) for non-construction ( $N$ ) and construction ( $C$ ) sectors, and by taking the ratio obtain,

$$\frac{A_{Nt}}{A_{Ct}} = \frac{\phi_N^{-\phi_N} B_{Nt}^{1-\phi_N}}{\phi_C^{-\phi_C} B_{Ct}^{1-\phi_C}} p_{lt}^{\phi_N - \phi_C} \quad (101)$$

where series of EU KLEMS sectoral TFP data are used as proxy for  $B_{Ct}$  and  $B_{Nt}$  and series of land prices (deflated by a consumption price index) from Davis and Heathcote (2007) as proxy for  $p_{lt}$ . The value of share of land in construction is taken from Davis and Heathcote (2005), which use a value which averages ten percent,  $\phi_C = 0.106$ .<sup>38</sup> Similarly, Kiyotaki, Michaelides, and Nikolov (2011) set the parameter governing the share of land so that it equals ten percent and cite Haughwout and Inman (2001), which document that the share of land in property income over the period 1987-2005 is about 10.9 percent. Regarding the share of land in non-construction,  $\phi_N$ , Iacoviello and Neri (2010) set such value to zero.  $\phi_N$  is set to several values over the range  $[0, 0.106]$  following the conjecture that non-construction industries are less land-intensive than construction.<sup>39</sup>

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<sup>38</sup>As discussed in Davis and Heathcote (2005), the share of land in new houses is set to 0.106 following the Census Bureau, specifically from an unpublished 2000 memo from Dennis Duke to Paul L. Hsen entitled "Summary of the One-Family Construction Cost Study".

<sup>39</sup>However it is worth mentioning that in the literature there is wide variation on the estimates of share of land across sectors. For example Valentinyi and Herrendorf (2008) estimates the land share in construction to be 3 percent, while the same figure for the overall economy is about 5 percent.

## D A very simplified framework to think about productivities and house prices

This section shows in a very simplified setup the mechanism through which a productivity slowdown in construction may affect house prices. Consider an economy with two sectors, housing and non-housing, respectively denoted by indices  $h$  and  $n$ . The housing sector produces houses, while the non-housing sector produces a non-housing good. Since the mechanism works via the supply of housing, here demands for houses and non-housing good are not modeled. Perfectly competitive firms in both sectors employ labor in production according to the following production functions

$$y_i = A_i e_i \quad i = n, h \quad (102)$$

where  $y_i$  and  $e_i$  denote sector- $i$  output and labor, while  $A_i$  is the labor productivity in sector  $i$ . To simplify the exposition, labor is freely mobile across sectors. Firms in each sector take as given prices and choose the amounts of labor to employ in production so to maximize profits. The first-order conditions for labor are given by

$$A_i p_i = w_t \quad i = n, h \quad (103)$$

where  $p_i$  is the price of houses if  $i = h$  and of non-housing good if  $i = n$ . Conditions (103) equate the marginal cost of labor to its marginal productivity in each sector. By combining these equations we get

$$\frac{p_h}{p_n} = \frac{A_n}{A_h} \quad (104)$$

which states that the relative price of houses is an increasing function of the ratio of productivity in non-housing over productivity in housing. That is, the sector with lower productivity will command higher prices. This mechanism has been emphasized in Baumol (1967), which introduced the idea that stagnant sectors, in the sense that their productivity grows at a lower rate than the rest of the economy, suffer from a *cost disease* which leads to increases in costs, and thus in prices, above the average of the economy.

## E Data

### US Nation level data

- **Sectoral productivities:** Data come from EU KLEMS, April 2013 release, Jorgenson, Ho, and Samuels (2012). Total Factor Productivity series (Series label: *TF-Pva\_I*) are based on value-added, hence is netted out of intermediates inputs use. Labor productivities are computed as ratios of a volume index of gross value added (*VA\_QI*) and either number of persons engaged (*EMP*) or total hours worked by persons engaged (*H\_EMP*). Sectoral productivities for the non-construction sector are computed as weighted averages of all sectors excluding construction. Weights are constructed from series on nominal value added (*VA*).
- **House prices:** Data on nominal prices come from Shiller (2005). Nominal prices are deflated using a PCE-based price index which excludes "Housing and utilities". PCE prices come from BEA (Table 2.3.4). Weights for constructing the price index are based on PCE expenditure shares. PCE expenditures come from BEA (Table 2.3.5).
- **Construction prices:** Data come from EU KLEMS April 2013 release, Jorgenson, Ho, and Samuels (2012). Data are at annual frequency. Gross value added price indices (code *VA\_P*) for construction (row *F*) are deflated using the price indices for Total Industries (row *TOT*).
- **Land prices:** Data come from Land and Property Values in the US, Lincoln Institute of Land Policy <http://www.lincolninst.edu/resources/> and is based on Davis and Heathcote (2007). Data are at annual frequency, prices are nominal. Land prices are deflated using the US national CPI index.
- **Residential investment over GDP:** Data come from Bureau Economic Analysis Table 1.1.5, annual frequency, current prices. Gross Domestic Product is row 1, residential investment is row 13. Since the model does not feature a government

sector, I exclude Government consumption expenditures and gross investment (row 22) from the calculation of Gross Domestic Product.

- **Current account over GDP:** Data come from Lane and Milesi-Ferretti (2007). Data are at annual frequency.

## Cross-country data

- **Sectoral productivities:**

1. EU KLEMS April 2013 release, Jorgenson, Ho, and Samuels (2012). Total Factor Productivity series (Series label:  $TFPva\_I$ ) are based on value-added, hence is netted out of intermediates inputs use. Labor productivities are computed as ratios of a volume index of gross value added ( $VA\_QI$ ) and either number of persons engaged ( $EMP$ ) or total hours worked by persons engaged ( $H\_EMP$ ). Sectoral productivities for the non-housing sector are computed as weighted averages of all sectors excluding construction. Weights are constructed from series on nominal value added ( $VA$ ).
2. World Input Output Socio Economic Accounts July 2014 release, Timmer, Erumban, Gouma, Los, Temurshoev, de Vries, and Arto (2012). Capital share for sector  $j$  is computed as

$$\alpha_j = 1 - \frac{1}{T} \sum_{t=1}^T \frac{LAB_{jt}}{VA_{jt}}$$

where  $LAB$  and  $VA$  respectively denote labor compensation and gross value added, both at current prices. TFP for sector  $j$  is computed as

$$TFP_{jt} = \frac{VA\_QI_{jt}}{K\_GFCF_{jt}^{\alpha_j} EMP_{jt}^{1-\alpha_j}}$$

where  $VA\_QI$  is real gross value added and  $K\_GFCF$  is real fixed capital stock, both at 1995 prices, and  $EMP$  is number of persons engaged. Non-construction TFP is constructed as weighed average of sectoral TFPs, where weights are constructed from series on nominal value added ( $VA$ ).

- **House prices:** Data on real house prices come from BIS Residential Property Price database in Mack and Martínez-García (2011) and from the database in Cesa-Bianchi (2013). Original data are converted to the yearly frequency by taking quarterly averages in the year.
- **Construction prices:** Data come from EU KLEMS April 2013 release, Jorgenson, Ho, and Samuels (2012), and World Input Output Socio Economic Accounts July 2014 release, Timmer, Erumban, Gouma, Los, Temurshoev, de Vries, and Arto (2012). Data are at annual frequency. Gross value added price indices (code  $VA\_P$ ) for construction (row  $F$ ) are deflated using the price indices for Total Industries (row  $TOT$ ).
- **Land prices:** Data come from BIS Residential Property Price database in Mack and Martínez-García (2011): for Austria is “LAND PRICES, RESIDENTIAL (VIENNA), PER SQUARE METER, Q-ALL NSA”, code “Q:AT:2:L:1:0:1:0”; for Belgium is “LAND PRICES, RESIDENTIAL, LAND FOR CONSTRUCTION, PER SQ.M,A-ALL NSA”, code “A:BE:0:L:1:1:1:0”; for Canada is “LAND PRICES, RESIDENTIAL, PER SQUARE METER, M-ALL NSA”, code “M:CA:0:L:1:1:1:0”; for Germany is “LAND PR, RESID, LAND FOR DETAC.1-FAM.HOUSE(WEST-G), PER SQ.M,A-ALL NSA”, code “A:DEZ1:R:L:1:2:1:0”; for Finland is “LAND PRICES, RESIDENTIAL, LAND FOR CONSTRUCTION, Q-ALL NSA”, code “Q:FI:0:L:1:1:1:0”; for Japan is “Land prices, residential, urban areas, per m2, NSA”, code “Q:JP”. Data for United Kingdom comes from Homes & Communities Agency, Summary of VOA residential development land surveys, January and July 2010. Data are converted at annual level and deflated using the CPI index.
- **Current account over GDP:** Data come from Lane and Milesi-Ferretti (2007). Data are at annual frequency.
- **Residential investment over GDP:** Data come from OECD National Accounts and is at annual frequency. Residential investment is the sum of subcomponents “Housing” (code P51PI64) and “Dwellings” (code P51N111) in “Gross fixed capital

formation" (code P51). GDP is Gross domestic product (expenditure approach), code B1\_GE.

## US States level data

- **Sectoral productivities:** Data come from BEA. Sectoral productivities are calculated as ratios of real sectoral value added (Table Real GDP by state, millions of chained 2005 dollars) and number of persons engaged (Table SA25N: "Total full-time and part-time employment"). Relative productivity in construction is calculated as labor productivity in construction over labor productivity of overall economy.
- **House prices:** Data come from Federal Housing Finance Agency (FHFA) and corresponds to the series "All-Transactions Indexes (Estimated using Sales Prices and Appraisal Data)". Original data are converted to the yearly frequency by taking quarterly averages in the year. House prices are deflated using the US national CPI index. Additional series on nominal house prices come from Land and Property Values in the US, Lincoln Institute of Land Policy <http://www.lincolninst.edu/resources/> and is based on Davis and Heathcote (2007). Data are at annual frequency. Prices are deflated using the US national CPI index.
- **Household debt per capita:** Data come from FRBNY Consumer Credit Panel. The data refer to the value of debt in the fourth quarter of the corresponding year. Household debt per capita is measured as the sum of "Auto Debt Balance per Capita", "Credit Card Debt Balance per Capita" and "Mortgage Debt Balance per Capita". Debt is deflated using the US national CPI index.
- **Land prices:** Data come from Land and Property Values in the US, Lincoln Institute of Land Policy <http://www.lincolninst.edu/resources/> and is based on Davis and Heathcote (2007). Data are at annual frequency, prices are nominal. Land prices are deflated using the US national CPI index.