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Reconstructing the Great Recession*

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Abstract

This paper evaluates the role of the construction sector in accounting for the performance of the U.S. economy before, during and after the Great Recession. We use input-output analysis to evaluate its linkages with the rest of the economy and measure the transmission of its demand shocks to the overall economy. Such effects are quantified by means of a dynamic multi-sector model parameterized to reproduce the boom-bust dynamics of employment in construction during 2000-13. The model suggests that the interlinkages account for a large share of the actual changes in aggregate employment and gross domestic product during the previous expansion, the recession and the subsequent recovery.

Keywords: Residential investment, multisector models, business cycle accounting
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1 Introduction

With the onset of the Great Recession U.S. employment and gross domestic product, together with other macroeconomic aggregates, fell dramatically and then took a long time to return to their historical trends. As there is still no consensus about what made the recession so deep and the following recovery so slow, we build on the input-output methodology to examine the role played by the construction sector. The construction sector collapsed as the real estate bubble burst in 2007 leading to a widespread financial crisis, an event commonly believed to be the key factor underlying the Great Recession and the poor economic performance that followed.

We claim that an important reason why the recession was particularly deep are the strong interconnection between housing and the rest of the economy. Hence, the sudden drop in the output of the construction sector translated into a general reduction of demand for most other sectors, and those interconnections propagated and magnified the initial demand shock. We also claim that the recovery was slow, among other things, because the irreversibility constraint on the stock of housing took quite a long time to be relaxed. Obviously, these two factors (interconnections and irreversibility) were not the only ones at play, as the literature reviewed below illustrates. But they are two quantitatively relevant ones worth exploring.

We will not model why housing prices first boomed and then collapsed (pulling the construction sector first up and then down with them) as this would lead us into a fairly undecidable debate. Be that as it may, there is general agreement that the collapse of home values translated into a sudden drop in the demand for a specific asset in which American households had, until then, invested a substantial portion of their wealth: residential housing. The analysis starts with this incontrovertible fact and studies the contribution of the construction sector to U.S. economic fluctuations in the last 25 years.

It is often argued that the housing sector is of great relevance to the aggregate economy because housing wealth is a major determinant of consumption demand (see Carroll et al. (2006), Case et al. (2005), and Mishkin (2007), among the most cited articles). An ample and somewhat more recent literature (e.g. Calomiris et al. (2009), Iacoviello (2011), and references therein) has cast doubts on the quantitative relevance of this channel for business cycles analysis. While the housing sector is certainly very cyclical, this is most likely not due to a causal chain going from housing wealth to consumption and aggregate demand to output, but to a host of other common factors driving such co-movements. Further, the same literature also reveals that, when empirical evidence of a causal link is found, the latter is not only quantitatively weak but its magnitude is also dependent upon demographic and financial variables. In the light of these findings on the demand channel, we explore here the supply route using a calibration approach. We argue that the macroeconomic relevance of the construction sector may derive from its interlinkages with many other sectors on the supply side. These linkages can propagate the effect of a decline in demand for residential investment to the rest of the economy and, by so doing, amplify it. Traditionally, most business cycle literature in the general equilibrium tradition has ignored the importance of the construction sector for aggregate fluctuations, in spite of the existence of a large empirical literature pointing in that direction.[1]

In our paper we provide both empirical evidence and a theoretical model describing the mechanism through which changes in constructions may be an important driver of aggregate

[1] Leamer (2007), just to name one among the dozens, argues that since World War II the U.S. economy has had eight recessions preceded by substantial problems in housing and consumer durables.

employment and output. The empirical analysis summarizes the role of the construction sector in the last three recessions, placing a special emphasis on the last one. Using data from the U.S. input-output tables, we construct measures of sectorial interlinkages (multipliers) and show that the construction sector is one of the most interconnected in the economy: changes in the construction of houses propagate immediately to most of the other sectors. We use this finding to quantify the contribution of constructions during the period 2002-2013 and estimate it to have been remarkably large: depending on the selected calibration, movements in the demand for housing account for between 1/4 and 1/2 of the total cyclical gyrations in aggregate output and employment.

To highlight the importance of the different channels, we first study a static multisector model to analyze the effects of a decline in housing demand. The model provides a set of sufficient conditions under which the presence of interlinkages generates larger effects in aggregate employment and output than in their absence. The model indicates that the sectoral interlinkages have to be asymmetric, that is the construction sector buys more from the rest of the economy than the other way around. Data show this is the case by almost two orders of magnitude. In an economy with symmetric sectors, the presence of linkages does not amplify to the rest of the economy the effects of a sectoral shock. The other factor important in propagating a sectoral shock to the rest of the economy is the complementarity between consumption and housing. A certain degree of complementarity (more than Cobb-Douglas) is necessary to generate a simultaneous decline in the demand of housing and non-housing consumption.[2] If both (sets of) goods have a very high degree of substitutability, then a decline in the (consumption of the good produced by the) construction sector can generate an increase in the consumption of everything else, which may (more than) compensate the decline due to the supply-side interlinkages. Still, the static model has several limitations: first, it does not allow studying the dynamic adjustment of consumption, residential investment, and productive capital. Second, it ignores the process of adjustment of relative prices.

To overcome these limits and, more importantly, to assess the quantitative relevance of sectoral interlinkages, we construct next a dynamic two-sector model in which construction is connected with the rest of the economy.[3] The presence of irreversibility constraints introduces an asymmetry between expansions and recessions.[4] During the expansion, the increase in the

[2] Davis and Heathcote (2005) construct a real business cycle with housing and interlinkages. In the baseline economy with Cobb-Douglas preferences, the presence of interlinkages generates a relatively small contribution to aggregate fluctuations in response to productivity shocks. Our theoretical model shows that Cobb-Douglas preferences completely eliminate the role of interlinkages because insufficient complementarity. This is true even when the sectoral linkages are asymmetric. Iacoviello (2005) generates house price fluctuations using shocks to Cobb-Douglas preferences, and the productive structure of the economy does not have interlinkages, but most of the action is driven by the presence of binding collateral constraints and price rigidities.

[3] The methodology in our paper is close to that of Davis and Heathcote (2005). They study the dynamics of residential investment and house prices in a multisector business cycle model. Their model is successful in reproducing the volatility of residential investment, but they do not focus on the propagation of demand shocks due to sectoral interlinkages.

[4] The analysis abstracts from both the increase in the burden of debt brought about by the decline in home prices (which is the focus of Garriga, Manuelli and A. Peralta-Alva, 2012*a*) and the reduction in credit activity it implied, two factors that are likely to have played a major role in the overall process. Although these factors could interact with the sectoral interlinkages, abstracting from them captures the contribution of the real side of the economy in the recession. In the model, a decline in the demand for homes generates a readjustment of the portfolio and a decline in the demand for intermediate inputs. The lower demand of intermediate goods deprives the real side of the economy and generates a significant decline in employment and real activity.

demand for housing results in unusually high growth in the rest of the economy, which, in our quantitative exercise, it is driven mostly by the induced demand for intermediate products that the construction sector creates. When the exogenous growth in housing demand stops such induced demand also comes to a halt, and the overall economy declines. This leaves the economy with a surplus of residential structures that are not easily transferable to activities other than housing. The relatively low depreciation of residential structures implies that home values, the construction sector, and aggregate consumption and investment take a long time to recover. The separation between the productive capital of the other sectors and housing structures is very important because the model predicts an initial decline of residential investment before the rest of productive investment declines. When the irreversibility constraint binds for a number of periods, the asymmetry between booms and busts is large. In addition, in the presence of demand complementarities, sectoral linkages interact with the final demand for goods other than housing. Hence, on top of the intersectoral linkages acting on the supply side, a decline in the demand for housing indirectly reduces the demand for complementary goods and, thus, the output from these sectors. As a result, the magnitude of the impact on output and total employment is amplified.

The goal of the extended model is to provide an estimate of the size of this impact, ignoring the importance of other relevant factors. We find it to be large enough to notice. To quantify the contribution of construction to the overall economy, we calibrate a sequence of demand shifters in consumer preferences to match the dynamics of employment in construction for different model specifications, with and without interlinkages. Qualitatively the effects are similar in these economies but, quantitatively, the magnitude of the boom-bust cycle in total employment and output is substantially larger with sectoral interlinkages. During the boom, both sectors expand and contribute to the growth of output and employment by 2 percent and 2.5 percent, respectively. During the housing bust, the magnitude depends on the number of periods the irreversibility constraint binds. When this effect is important, the decline in output is 3.3 percent, and 3.8 percent in employment. For a lower degree of complementarity, the asymmetric effect is not as large but still significant. To quantify the role of interlinkages, we perform two exercises in which they are absent. In these cases, changes in housing demand consistent with the dynamics in construction employment have only a small impact on the other macroeconomic quantities even when demand complementarity between consumption goods and housing is high. The model without linkages also fails to capture the lead-lag pattern of housing and consumption expenditures observed in the data. From this finding we infer that modeling the input-output linkages matters for quantitative business cycle analysis.

In our simulations, all changes in employment and output are generated only by variations in housing demand; we purposefully ignore any other shock such as those to sectoral productivity, financial restrictions and labor search and match. The counterfactual allows us to estimate confidence intervals of the quantitative importance of variations in demand for housing for the overall economy. During the expansion, between 2002 and 2007, the construction sector accounts for a significant share of growth of employment (between 29 and 61 percent) and GDP (between 8 percent and 15 percent of the total). More importantly, its contribution during the Great Recession is between 28 percent and 43 percent of employment and between 43 percent and 60 percent of GDP.

The burst of the real estate "bubble" might have substantially lowered potential output and created a substantial "displacement effect", for both labor and capital, which took quite some time to absorb. Some researchers have referred to this displacement effect as a worsening of the labor frictions. For example, Arellano et al. (2010) and Ohanian and Raffo (2012) attribute most of the recession to this factor. Since our model captures a significant decline in employment and output in the absence of such "frictions", we also perform a business cycle accounting exercise on simulated data from the model. Our model has no friction, but the intersectoral linkages, the movements of relative prices and the induced variations on the demand for labor are interpreted as "distortions" through the lens of the one-sector neoclassical growth model. This methodology would attribute the recession, in our model, to the labor wedge. The magnitude of the worsening of the labor wedge is about 62 percent of the total change observed in the data. Importantly, in both our model and the data the worsening is due to the consumer side of the labor wedge and not to differences between wages and the marginal product of labor.

Note that the causal links discussed here operate in an environment not subject to the market failures and price-adjustment frictions now standard in business cycle models used to guide fiscal and monetary policy. In the language of those models, ours is a model of potential output in which fluctuations of economic activity cannot be counteracted with standard policy tools. Our findings are important for policy discussions because they imply that output gaps may not be as large as previously thought.

Obviously, the gyrations of the construction sector cannot fully account for the dynamics of employment and output since 2002. Other relevant factors not incorporated in the analysis are important. Many suggest (Black, 1995; Hall, 2011; Kocherlakota, 2012) that high interest rates could be responsible for the slow recovery. These authors argue that even in models with perfect competition and price flexibility (i.e., lacking the typical frictions of New-Keynesian business cycle models), too-high interest rates may result in substantially lower levels of output and employment. Since some interest rates appear to be currently constrained by the zero lower bound, such analyses appear particularly pertinent. Others argue that the level of uncertainty (Bloom, 2009; Arellano et al., 2010), government policies (Herkenhoff and Ohanian, 2011), and excessive debt overhang in the economy (Garriga, Manuelli and A. Peralta-Alva, 2012*a*,*b*; Herkenhoff and Ohanian, 2012; Kehoe et al., 2013) may be responsible for the lackluster recovery.

The remainder of the paper is organized as follows. In section 2, we connect our work with the related literature. In section 3, we perform standard calculations using the input-output matrix of the U.S. economy and present a simple static model of interdependence that is used to illustrate the key mechanism at work in the analysis. Section 4 presents the quantitative model, the results, and the robustness analysis. Section 5 compares the implications of the model in terms of business cycle accounting methodology, and Section 6 offers some concluding comments.

2 Related Literature

Our research is related to several strands of the literature. In this section we highlight the differences between this paper and those areas of research.

There is a large literature studying the connection between housing and the macroeconomy. Some examples include Gervais (2002), Iacoviello (2005), Campbell and Hercowitz (2005), Davis and Heathcote (2005), Leamer (2007), Fisher (2007), and Davis and Van Nieuwerburgh (2015). None of these papers specifically addresses the contribution of housing to the Great Recession in the context of a fully specified general equilibrium model and, in particular, no paper addresses directly the issue of intersectoral linkages.

There is now a growing literature arguing that the sectoral composition is an important source of propagation of idiosyncratic sectoral shocks (i.e., Horvath (1998), Horvath (2000); Carvalho (2010); Foerster et al. (2011); Gabaix (2011); Acemoglu et al. (2012) Carvalho and Gabaix (2013); Caliendo et al. (2014); Acemoglu et al. (2015); Atalay and Drautzburg (2015)).[5] In the previous literature using this methodology, the idiosyncratic shocks must change the shape of the production possibility frontier, hence relative prices, to generate large aggregate effects. We believe this is a very important channel through which sectoral shocks drive aggregate fluctuations, probably the most important in the long run. Nevertheless, as our main concern is with the Great Recession we find it hard to point to a specific "sectorial production possibility shifter" in this instance. Here, common sense joins economic analysis to suggest that a dramatic drop in housing demand, induced by the bursting of the price bubble, was by far the dominant shock. Our analysis takes this fact as given and studies the propagation to the rest of the economy even in the absence of technological shocks.

Most of the literature makes no attempt to measure the specific role of construction and residential investment in the Great Recession episode. One notable exception is Li and Martin (2014) that studies the transmission of aggregate and sectoral shocks using dynamic factor methods and explicitly looks at input-output linkages to estimate the intratemporal transmission of shocks letting the data provide estimates for the intertemporal ones. Their findings suggest that a significant part of traditionally defined aggregate fluctuations are driven by sector-specific shocks. However, as far as the Great Recession is concerned, more than half of aggregate volatility is accounted for by an additional aggregate shock - which they label the "wedge factor" - emerging only during this period. Most crucially, and consistently with our bottom line, they find that shocks originating in the construction sector generate the largest spillover effects over time, dominating that of all the other sectors. We believe that their findings and ours are related and should be interpreted in the light of the "simulated wedge" exercise we perform in Section 5. The findings in our model are also consistent with Kehoe et al. (2016) that document that the drop in employment in the regions that have experienced the largest decrease in household debt is mostly accounted for by changes in the labor wedge (deviations from a static consumption-leisure choice) as opposed to changes in real wages. In our model (real) wages are nearly constant and the changes in employment are driven by the construction sector (aka labor wedge).

There is also an extensive literature that explores the role of financial conditions as drivers of the Great Recession and of the delayed recovery using quantitative dynamic macroeconomic models (i.e., Black (1995); Bloom (2009); Christiano et al. (2010); Arellano et al. (2010); Gertler and Karadi (2011); Hall (2011); Midrigan and Philippon (2011); Kocherlakota (2012); Jermann and Quadrini (2012); Brunnermeier and Sannikov (2013); He and Krishnamurthy (2014); Mitman et al. (n.d.)). Most of the literature abstracts from the role of housing during this episode, with a few exceptions. Among them is Garriga, Manuelli and A. Peralta-Alva (2012*a*). In their model an increase in the cost of housing financing generates a collapse of house prices, inducing a recession through deleveraging. Similarly, Hatchondo et al. (2015) and Hedlund (2015) use heterogeneous agent models to analyze the aggregate effects of a house

[5]The traditional view of the business cycle literature is that idiosyncratic sectoral shocks are likely to average out and have no aggregate effects as the number of sectors in the economy gets larger (i.e., Lucas (1981); Kydland and Prescott (1982); Long and Plosser (1983); Dupor (1999)).

price decline and of its propagation to the rest of the economy through the households' balance sheets and housing defaults. Iacoviello and Pavan (2013) argue that a tightening of households' budgets, due to the drop in real estate wealth, induced a sharp decline in aggregate consumption. Simsek et al. (2014) explore the aggregate effect of an insufficient housing demand resulting from a period of overbuilding. Our paper is complementary to this literature because, once again, we take as given the drop in housing demand and then study its supply-side propagation due to sectoral interlinkages.

3 Construction in an Input-Output Economy

This section provides empirical evidence first, and then, a simple theoretical framework that allow us to work out analytically the importance of interlinkages. The data analysis places special attention on the Great Recession, but also uses detailed US sectorial input-output data for the period 1990-2013. The theoretical framework provides a set of sufficient conditions for the amplification mechanism to work.

3.1 Construction and Aggregate Fluctuations: 1990-2013

For the analysis of economic fluctuations it is common to use aggregate data for the whole postwar period. Unfortunately, the current availability of uniform input-output data is limited to the years 1990-2014. According to the National Bureau of Economic Research (NBER), the U.S. economy has experienced three recessions (1990-91, 2000-01, 2007-09) during that interval of time. To evaluate the *direct contribution* of construction to each episode, Table 1 summarizes the change in employment and real income for construction and the private sector. The top panel of Table 1 reminds us that the 1990-91 recession was rather mild: between the peak of 1990-Q3 and the trough of 1991-Q1 employment and income declined by less than 1 percent. In relative terms the decline in construction was sizeable: slightly less than 6 percent for employment and more than 7 percent for income. The middle panel of Table 1 shows the recession that started in 2000-Q1 and ended in 2001-Q4. This recession was slightly more severe than the previous one: employment fell by more than 1 percent and income by more than 2 percent. However, the decline in construction was almost negligible and the share of the aggregate decline it accounted for, was small.

The Great Recession started in 2007:Q4 and lasted until 2009:Q2. During this period, total employment decreased by roughly 8 million jobs. Table 1 shows that the drop in construction employment and value-added account for about 20 percent of the total. This recession was dramatically bigger than the previous two and the drop in employment almost an order of magnitude larger.

In our calculations we ignore the fact that construction leads the cycle: we do this to simplify both the modeling strategy and the simulations, but this choice hampers the estimation of the quantitative relevance of constructions in the cycle. During the Great Recession the construction industry went into recession 18 months before the overall economy. Measuring the decline from the perspective of the construction cycle shows that employment fell from 7.7 million (2006:Q3) to 5.5 million (2011:Q1) and recovered little thereafter. Figure 1 shows that employment, gross output, and GDP in the construction sector dropped about 30 percent during this period, with the largest year-to-year decline between 2008 and 2009.

Since construction leads the cycle, measuring the decline between the sectoral peak-trough amplifies it: Figure 1 says that the overall decline was around 30 percent instead of the 20 percent suggested in Table 1. Another important aspect is its size relative to the rest of the economy. The share of construction in total GDP fluctuates around 4.5 percent, whereas its employment share is slightly larger, around 5 percent. The fact that the employment share is higher than the one for GDP reflects the fact that construction is relatively more labor intensive than the rest of the economy, which is just another way of saying that average labor productivity in construction is below the economy-wide mean.

3.2 Evidence and Implications of Production Interlinkages

This section uses U.S. sectorial input-output data, for the period 1990-2013, to estimate the role of construction in accounting for aggregate fluctuations. Despite its relatively small size, the contribution of the construction sector to this recession was a combination of two factors: the large size of the shock affecting it and its strong interlinkages with other sectors.[6] One way of measuring the importance of construction's interlinkages is through its purchases from other sectors as a percentage of those sectors total output. These are reported in Figure 2. As we all know, this only measures the *direct impact* (first round effect): because each sector purchases goods and services from other sectors as inputs, the process continues, virtually, for an infinite number of steps until it converges, thereby inducing a "production multiplier" effect. This multiplier effect is measured in the units depicted in Figure 2. However, using the requirement matrices from the BEA input-output tables it is possible to calculate the *total effect* of changes in the demand for a specific sector on the aggregate economy and on each of its sectors.

How does a \$1 decline in the final demand of sector x affect aggregate employment and gross output? Figure 3 ranks sectors according to such multipliers. In terms of gross output, the two sectors with the largest multipliers are manufacturing (2.4) and agriculture (2.3). Construction has the third largest production multiplier: a \$1 decline in the final demand of the construction sector generates (absent changes in relative prices and in the composition of final demand) a \$2.1 decline in gross output. But recall that the construction sector is larger than agriculture, its final demand is much more volatile than that of both manufacturing and agriculture and its output composition is much more homogeneous. In terms of employment, the construction sector also has a relatively large multiplier. It is worth noting that with respect to employment, the multipliers of the manufacturing and agriculture sectors are not as significant. This leaves the construction sector with one of the largest employment and gross output multipliers.

From a quantitative perspective, one would like to understand how significant these multipliers are when it comes to aggregate fluctuations. A simple way to do this is to compare the actual evolution of the U.S. economy with that of an artificial economy in which the fluctuations in the construction sector are eliminated by working through the whole series of interlinkages. To do this we use the requirement matrices and compare the actual evolutions of U.S. employ-

[6] In the analysis hereafter, the definition of the construction sector does not include "real estate and leasing" because the "construction" sector is. technologically, quite different from "real estate and leasing." The analysis performed including this additional sector in the definition of construction increases the significance of the latter in accounting for the Great Recession.

ment and gross output with those in a fictional economy without the construction sector.[7] The difference between these paths is a rough first-order estimate of the aggregate impact of the construction sector. Figure 4 shows that the dynamics of employment and gross output for the two economies are very different.

When construction is included, total employment increases about 6 percent between 2002 and 2006, which is then entirely lost. In contrast, the economy without a construction sector has a slower recovery from the 2001 recession; employment growth picks up only in 2005 and employment destruction starts in 2009. The magnitude of the subsequent decline is half of that actually experienced. Unlike in the actual economy, employment starts recovering already in 2010 and surpasses the previous peak in 2012. This exercise shows that the construction sector contributed greatly to employment growth between 2002 and 2005, and to employment destruction during the Great Recession. A slight weaker conclusion can be drawn by analyzing the series for gross output. This simple decomposition using the input-output framework reveals that during the Great Recession construction accounted for 52 percent of the decline in employment and 35 percent of the decline in gross output.

The previous analysis estimated the interaction between construction and the aggregate economy. At a more micro level construction interacts differently with the various sectors in the economy. Therefore, a decline in the activity of the construction sector will have a larger impact on those sectors that sell to it directly as opposed to those that do not. To show this Figure 5 reports, for each sector, two statistics: the actual sectoral declines in gross output and employment between 2006-09 and 2007-09, and those estimated using the input-output matrix, for the same period, as a consequence of the observed decline in construction.[8] The blue and green bars in Figure 5 represent the historical percent changes in gross output and employment for 13 industries and for the total economy. Gross output for the construction sector and for the aggregate (total nonfarm) declined by 21.3 percent and 6.2 percent respectively. Employment in construction decreased by roughly the same amount as gross output, 21.5 percent, while aggregate employment declined by 4.4 percent. The aggregate numbers are slightly larger when considering the period 2007-09. The yellow bars represent the decline attributable to the decline in the construction sector on the basis of the input-output multipliers (for gross output and employment, respectively). For example, according to this methodology the drop in construction accounts for a significant part of the gross output decline in mining, about 68 percent, while it accounts for little of the decline in retail trade.

According to this methodology, construction is capable of accounting for about 35 percent of the decline in aggregate gross output and for about 52 percent of the decline in aggregate employment. These numbers contrast with the direct impact estimates, which account for 20.8 percent of the decline in employment and 19.3 percent in income, as shown in Table 1. The difference between the direct and the total effect is due to the magnifying role of the production interlinkages; this is what we label the production multiplier.

The construction sector played an important role not only in the recession, but also in the subsequent slow recovery. This can be studied by performing an input-output exercise

[7] To construct the counterfactual we use every year available in the Bureau of Economic Analysis (BEA) and Bureau of Labor Statistics (BLS) requirement tables. We use them to calculate the impact of demand for the output of the construction industry on total gross output and employment. Those values are then removed, together with the values of the construction industry per se, from the aggregate gross output and value added of the U.S. economy, year by year. In the figure construction includes real estate and leasing.

[8] For employment, the "employment requirement matrix", from the Bureau of Labor Statistics (BLS), is used.

similar to that in Figure 5 for the recovery period in 2009-2011. In particular, Figure 6 shows the simulated growth rate of different sectors under the assumption that, from 2009 onward, construction grows at pre-recession rates. The blue bars display the actual changes of gross output and employment in 13 industries and in the total economy (total nonfarm). They show that between 2009 and 2011 gross output increased by 5 percent and employment increased by roughly 1 percent. The yellow bars represent the counterfactual simulation and show that if construction had grown at its pre-recession levels, total gross output and employment would have increased by 6 and 2 percent respectively. The industries that would have grown the most in terms of gross output, in this scenario, are wholesale trade (20 percent), retail (10 percent), mining (13 percent), and transportation and warehousing (11 percent). These findings indicate that the contribution of the construction sector to the dynamics of aggregate employment and output are non-trivial. The next section proposes a simple model of interlinkages that explains the nature of these effects.

3.3 A Simple Model of Interlinkages

The model studied here is a simplified version of the more complex model of Section 4. Consider a perfectly competitive economy with two sectors (goods and housing) and a representative consumer. Individual preferences are defined over consumption, c, housing/structures, h, and total employment, n, and represented by a utility index $U(c, \theta h, n)$. This function satisfies the usual differentiability and concavity properties. The budget constraint of the representative consumer is $c + ph = wn$ where w is the wage rate and p the price of housing, both measured in units of the consumption good (the numeraire).

Each good is produced in its sector and the production processes are subject to sectorial interlinkages. Part of the output of the consumption sector, m_y, is used as an input to produce homes, and part of the output of the housing sector is used to produce consumption goods, m_h. The gross output flows of the two sectors are $c + m_y = Y = A_y f(n_y, \varepsilon_y m_h)$, and $h + m_h = H = A_h g(n_h, \varepsilon_h m_y)$ where A_j represents the productivity of sector $j = y, h$.[9] The ε_j terms, $j = y, h$, capture the relative importance, in sector j, of the intermediate inputs from the other sector. Aggregate labor satisfies the restriction $n_y + n_h = n$. Free mobility implies that the wage rate is the same across sectors.

A *competitive equilibrium* in this economy is an allocation $\{c, h, n, n_y, n_h, m_y, m_h\}$ and prices $\{w, p\}$ that solve i) the optimization problem of the consumer, ii) the optimization problem of the firms in each sector, and, iii) the market clearing conditions.

As a function of the preferences (θ) and technology (ε) parameters, value added in this economy is defined as

$$VA(\theta, \varepsilon) = c(\theta, \varepsilon) + p(\theta, \varepsilon)h(\theta, \varepsilon).$$

The goal is to identify conditions under which a shift $\triangle\theta = \theta' - \theta$ in the demand for housing has a larger impact on total employment and value added in the presence of interlinkages ($\varepsilon > 0$)

[9] For expositional purposes, in this section we assume that the diagonal coefficients of the requirement matrix A, in the Leontief model, are zero. The general formulation would be $c + m_{yy} + m_{yh} = Y = A_y f(n_y, \varepsilon_{yy} m_{yy}, \varepsilon_{yh} m_{hy})$, and $h + m_{hy} + m_{hh} = H = A_h g(n_h, \varepsilon_{hy} m_{yh}, \varepsilon_{hh} m_{hh})$ where, in each m_{ij}, the first subscript denotes the origin (i) and the second denotes the destination (j).

than without ($\varepsilon = 0$), i.e. the conditions under which we have

$$\frac{\partial VA(\theta,\varepsilon)}{\partial\theta} \geq \frac{\partial VA(\theta,0)}{\partial\theta}.$$

There are three interacting channels through which a change in the demand for housing (as parameterized by θ) may affect value added: (1) a direct change in the desired quantities of c and h, (2) a change in their relative prices (and the consequent second-order changes in the quantities demanded), (3) a change in the supply of labor due to both wealth and price effects. In the following examples we try to isolate each one of the three channels while, in the more complex model of Section 4, we use quantitative methods to measure the overall impact.

3.3.1 Example: Leontief Production

A simple way to eliminate the price effects is to consider an economy in which both production functions are fixed coefficients, as in

$$c + m_y = Y = A_y \min\{n_y, \frac{m_h}{\varepsilon_y}\},$$
$$h + m_h = H = A_h \min\{n_h, \frac{m_y}{\varepsilon_h}\}.$$

The parameters $\varepsilon_y \geq 0$ and $\varepsilon_h \geq 0$ capture the intensity of the sectoral interlinkages.[10] Non-substitutability and the aggregate employment constraint can be used to compute a linear production possibility set

$$c + \left(\frac{A_y + \varepsilon_h}{A_h + \varepsilon_y}\right) h = \left(\frac{A_y A_h - \varepsilon_y \varepsilon_h}{A_y + \varepsilon_h}\right) n$$

where $A_y A_h > \varepsilon_y \varepsilon_h$ must hold. If the intermediate input requirements are too high, relative to the productivity of each sector, it would not be feasible to produce positive amounts of consumption and housing.[11] The linearity of the production possibility frontier implies that the relative price of construction only depends on technical coefficients,

$$p = \frac{A_y + \varepsilon_h}{A_h + \varepsilon_y}.$$

[10] As $\varepsilon_j \to 0$, the required quantity of the intermediate good converges to zero, $m_j \to 0$. When both coefficients converge to zero, the technology to produce goods becomes $c = A_y n_y$ and the technology to produce construction is $h = A_h n_h$. In this case, the interlinkages disappear.

[11] This condition is the well-know "all-or-nothing" property of Leontief input-output models. When it is met, the economy is productive and any non-negative value-added is reachable if enough labor input is available.

In the model without interlinkages $\varepsilon_j \to 0$, the price of housing is given by the ratio of productivities $p = A_y/A_h$. Similarly, wages are determined by

$$w = \left(\frac{A_y A_h - \varepsilon_y \varepsilon_h}{A_y + \varepsilon_h} \right).$$

In this setting, exogenous changes in housing demand, $\triangle\theta$, have no effect on prices and wages: all the macroeconomic effects are driven by changes in quantities. Value added becomes

$$VA(\theta, \varepsilon) = c(\theta, \varepsilon) + ph(\theta, \varepsilon).$$

Two simple specifications serve as useful benchmarks for the cases in which a change in the housing demand shifter $\triangle\theta$ is not amplified via interlinkages. The first one ignores sectorial interlinkages, $\varepsilon_y = \varepsilon_h = 0$, and the model collapses to one in which relative prices and wages are determined by factor productivities only. The second one considers perfectly symmetric sectors, $\varepsilon_y = \varepsilon_h = \varepsilon$ and $A_y = A_h = A$, implying steady state prices and wages equal to $p = 1$ and $w = (A - \varepsilon)$. One can easily add a third trivial case where the consumption good is completely independent of θ, that is $c(\theta, \varepsilon) = c(\varepsilon)$.

Case 1: Preferences with Perfect Complementarity (No substitution) This specification allows the housing demand shifter $\triangle\theta$ to change directly the consumption demand of both goods. The utility index is given by

$$U(\theta c, h, n) = \min\{\theta c, h\} - an^{1+\gamma}/(1+\gamma)$$

This corresponds to the extreme case of perfect complementarity, but only some degree of complementarity (less than unitary elasticity of substitution between c and h) is sufficient for the mechanism to operate. With this utility function consumption is given by

$$\widehat{c} = \left[\frac{A_y A_h - \varepsilon_y \varepsilon_h}{(A_h + \varepsilon_y) + \theta(A_y + \varepsilon_h)} \right] n.$$

and the demand for housing is just $\widehat{h} = \theta\widehat{c}$. In the model without interlinkages ($\varepsilon_j = 0$) employment is allocated in the two sectors according to $\widehat{n}_h^{nolink} = A_y n/(A_y + \theta A_h)$.

Solving for the aggregate level of employment yields

$$\widehat{n} = \left[\frac{\theta}{a} \left(\frac{A_y A_h - \varepsilon_y \varepsilon_h}{(A_h + \varepsilon_y) + \theta(A_y + \varepsilon_h)} \right) \right]^{\frac{1}{\gamma}},$$

whereas in the absence of interlinkages the employment level is

$$\widehat{n}^{nolink} = \left[\frac{\theta}{a}\left(\frac{A_y A_h}{A_h + \theta A_y}\right)\right]^{\frac{1}{\gamma}}.$$

Measured economic activity is given by

$$VA = c + ph = \left[\frac{A_y A_h - \varepsilon_y \varepsilon_h}{A_y + \varepsilon_h}\right]\widehat{n}(\theta).$$

Notice that value added is proportional to total employment and the scaling factor does not depend on the parameter θ. The change in value added due to a change in housing demand driven by $\triangle\theta$ is

$$\frac{\partial VA}{\partial \theta} = \left[\frac{A_y A_h - \varepsilon_y \varepsilon_h}{A_y + \varepsilon_h}\right]\frac{\partial \widehat{n}(\theta)}{\partial \theta}.$$

We ask next: how do changes in the preference parameter θ affect aggregate employment, n, and value added, VA? Notice first, from the formulas above, that the economy with interlinkages and the one without have different levels of aggregate employment. Hence, we will compute the two elasticities of employment with respect to variations in θ.

In the model with interlinkages, this elasticity is

$$\epsilon_{n,\theta} = \frac{1}{\gamma}\left[\frac{A_y + \varepsilon_h}{(A_h + \varepsilon_y) + \theta(A_y + \varepsilon_h)}\right] > 0,$$

and in the economy without linkages it is

$$\epsilon_{n,\theta}^{nolink} = \frac{1}{\gamma}\left[\frac{A_y}{A_h + \theta A_y}\right] > 0.$$

The presence of interlinkages amplifies the effect of any given preference shock when, $\epsilon_{n,\theta} > \epsilon_{n,\theta}^{nolink}$, which reduces to $A_h\varepsilon_h > A_y\varepsilon_y$ after a bit of algebra.[12] This is clearly satisfied when the construction sector purchases intermediate inputs from the rest of the economy ($\varepsilon_h > 0$), but not the other way around ($\varepsilon_y = 0$). Hence, in general, the condition holds (for given levels of sectoral productivities) when the construction sector absorbs lots of inputs from the other sector but the other sector does not use housing as an intermediate input, which does not sound so unrealistic. Notice that the condition fails when the sectors are symmetric. This is consistent with the earlier theoretical results of Horvath and Dupor.

Does the empirical evidence support this asymmetry? We have used the direct input requirement matrix to carry out a back-of-the-envelope test of the key inequality. We aggregated the matrix into a 2x2 format: construction and everything else. Next we eliminated the "own intermediate inputs", that our model assumes away for simplicity, and collapsed the value added of each sector as labor income. We used the sectoral price indices to compute the relative price

[12] This condition is related to the irrelevance result in Dupor (1999).

p during the available sample period and used this information to compute, by simple algebra, the 4 parameters of our model. We found that $A_h \varepsilon_h / A_y \varepsilon_y$ equals 636, after rounding up. The inequality is amply satisfied, thereby suggesting, on the basis of this admittedly simplified model, that in the real world the magnification effects of asymmetries are likely to be present.

Case 2: Unitary Elasticity To highlight the importance of the complementarity between c and h, we consider the case of Cobb-Douglas preferences,

$$u(c,h) = \log c + \theta \log h.$$

Assuming the production functions are the same as in the previous example, it is a matter of algebra to check that the employment level with linkages is always larger than without, $n = \omega n^{nolink}$ where $\omega > 1$. Here, though, the scaling factor is independent of θ, that is $\partial\omega/\partial\theta = 0$, and, as a result, with and without interlinkages the elasticity of employment is the same

$$\epsilon_{n,\theta} = \epsilon_{n,\theta}^{nolink} = \frac{1}{1+\gamma}(\frac{\theta}{1+\theta}).$$

For this reason, in the quantitative exercise of Section 4.5 we adopt a preference specification that has more complementarity than Cobb-Douglas.

4 Dynamic Analysis

The previous model is static and very stylized and, although it may give reasonable predictions in the very short-run (i.e., on impact of a given shock or change in relative prices), it may also become less reasonable when the time horizon is increased to more than a couple of quarters. Simulating the path of an economy over time by linking a sequence of static input-output matrices ignores the optimal response of the agents and the general equilibrium effects they bring about. The dynamic model presented in this section is a generalization of the static model as far as preferences and technology are concerned. It also introduces an irreversibility constraint in the use of housing structures, which, as we will show, generates an empirically crucial asymmetry between expansions and recessions.

4.1 Households

The total population size, N_t, is normalized to 1. Household preferences are defined by a time-separable utility function, $u(c_t, \theta_t h_t) + \gamma v(1 - n_t)$, where c_t represents consumption goods, h_t represents housing services, n_t represents labor supplied in the market, and $\gamma > 0$ represents the relative weight of leisure in preferences. Housing provides utility, and it is complementary to goods consumption. The shifts in housing consumption are driven by adjustments in the parameter, θ_t. The utility functions u and v satisfy the usual properties of differentiability and concavity. The sequence of utilities is discounted by the term $\beta \in (0, 1)$. Housing services are produced according to a technology, $H(s_t, l_t)$, that combines physical structures, s_t, and land, l_t. The technology has constant returns to scale and satisfies $H_i' > 0$, $H_i'' < 0$, and $H_{ij}'' > 0$. Housing structures depreciate at a constant rate, δ_s. In each period, the numeraire is the spot price of the manufacturing good. The household also invests in structures used by firms, to which they are rented as a capital input. All investment decisions are subject to an irreversibility constraint and have different depreciation rates in the two sectors. Formally, the representative consumer chooses $\{c_t, h_t, n_t, k_{t+1}, s_{t+1}, l_{t+1}\}_{t=0}^{\infty}$ to maximize

$$\max \textstyle\sum_{t=0}^{\infty} \beta^t [u(c_t, \theta_t h_t) + \gamma v(1 - n_t)],$$

$$s.t. \qquad c_t + x_t^k + p_t^s x_t^s = w_t n_t + r_t^k k_t + p_t^l (l_t - l_{t+1}) + \pi_t,$$

$$h_t = H(s_t, l_t), \tag{1}$$

$$x_t^k = k_{t+1} - (1 - \delta_k) k_t \geq 0, \tag{2}$$

$$x_t^s = s_{t+1} - (1 - \delta_s) s_t \geq 0, \tag{3}$$

together with the transversality and the no-Ponzi-game conditions. The prices are defined as follows: p_t^s is the price of infrastructure, p_t^l is the price of land, w_t represents the wage rate, and r_t is the gross return on capital. To facilitate computing the rental rate for housing services, our specification allows land trading, l_t, even if in equilibrium there is no trading of land, which is owned by the representative household and inelastically supplied. The term π_t represents profits from the non-housing sector.

The relevant first-order conditions of the consumer problem are

$$\frac{\gamma v'(1 - n_t)}{u_c(c_t, \theta_t h_t)} = w_t, \forall t,$$

$$\frac{u_c(c_t, \theta_t h_t)}{\beta u_c(c_{t+1}, \theta_{t+1} h_{t+1})} = 1 + r_{t+1}^k - \delta_k, \forall t,$$

when the irreversibility constraints do not bind, $x_t^k > 0$. When the investment in housing is positive ($x_t^s > 0$) the relevant first order conditions satisfy

$$\frac{u_h(c_t, \theta_t h_t)}{u_c(c_t, \theta_t h_t)} = R_t, \qquad \forall t,$$

$$p_t^s = \frac{1}{1 + r_{t+1}^k} [R_{t+1} H_s(s_t, l_t) + p_{t+1}^s (1 - \delta_s)],$$

$$p_t^l = \frac{1}{1 + r_{t+1}} [R_{t+1} H_l(s_t, l_t) + p_{t+1}^l],$$

where R_t represents the implicit rental price for housing services measured in terms of consumption units. Notice that a no-arbitrage condition holds between investment in land and housing. The last two expressions state that the current cost of purchasing a unit of housing structures (land) equals the future return of housing services derived from the housing capital (land) valued at market prices, plus its capitalization.

4.2 Consumption Sector

We assume a simple input-output structure: to operate each sector requires, among other things, part of its own output and of that of the other sector as intermediate inputs. To capture this fact, we deviate from common practice and write all production functions in terms of gross (as opposed to net, i.e., value-added) output, at least initially. Capital goods, which are produced in the consumption (or manufacturing, we use the two terms interchangeably, asking forgiveness for the imprecision) sector, must be distinguished from the intermediate inputs from the same sector since they last more than one period. In the baseline model, capital goods (physical capital and business structures) are used in the manufacturing sector. Both investments satisfy the putty-clay assumption on sector-specific investment.

Formally, let $m^{i,j}$ be the intermediate input produced by sector i and used by sector j. The manufacturing sector operates in a competitive market and uses the technology $A_t^y F(k_t, n_t^y, m_t^{y,y}, m_t^{s,y})$ to produce its gross output:

$$Y_t = c_t + x_t^k + m_t^{y,y} + m_t^{y,s}.$$

The production function F is constant returns to scale. The firm's optimization problem is

$$\begin{aligned} \pi_t^y = & \max_{k_t, n_t^y, m_t^{y,y}, m_t^{s,y}} Y_t - w_t n_t^y - r_t^k k_t - m_t^{y,y} - p_t^s m_t^{s,y}, \qquad \forall t, \\ & s.t. \qquad Y_t = A_t^y F(k_t, n_t^y, m_t^{y,y}, m_t^{s,y}), \qquad \forall t, \end{aligned}$$

where the price of manufacturing's output is normalized to 1. The constant returns to scale assumption implies zero equilibrium profits, $\pi_t^y = 0$, and marginal cost pricing for each input

$$\begin{aligned} r_t^k &= A_t^y F_1(k_t, n_t^y, m_t^{y,y}, m_t^{s,y}), \\ w_t &= A_t^y F_2(k_t, n_t^y, m_t^{y,y}, m_t^{s,y}), \\ 1 &= A_t^y F_3(k_t, n_t^y, m_t^{y,y}, m_t^{s,y}), \\ p_t^s &= A_t^y F_4(k_t, n_t^y, m_t^{y,y}, m_t^{s,y}). \end{aligned}$$

4.3 Construction Sector

The construction sector is also competitive. Its net output consists of residential structures, purchased by the households, while its gross output also includes structures used as an intermediate input in both sectors. In the baseline case, purely for simplicity, we assume this sector has a fixed stock of capital; hence its value added is split between the wages of labor and the rent accruing to the owner of the fixed capital stock (the representative households). Implicit in this formulation is a somewhat extreme assumption about the mobility of factors from one sector to another: While labor can move freely, the stock of capital invested in the construction sector is completely immobile (either way), and variations in investment activity have an impact only on the manufacturing sector. The technology for gross output is represented by,

$$X_t^S = x_t^s + m_t^{s,s} + m_t^{s,y} = A_t^s G(n_t^s, m_t^s(m_t^{s,s}, m_t^{y,s})),$$

and exhibits decreasing returns to scale in labor and the intermediate input mix. In the benchmark economy, we assume $G(\cdot)$ is a constant elasticity of substitution (CES) production function and the intermediate inputs aggregator is Cobb-Douglas. The optimization problem of the representative firm is now

$$\pi_t^s = \max_{n_t^s, m_t^{s,s}, m_t^{y,s}} p_t^s X_t^S - w_t n_t^s - p_t^s m_t^{s,s} - p_t^y m_t^{y,s}, \qquad \forall t,$$
$$s.t. \qquad X_t^S = A_t^s G(n_t^s, m_t^s(m_t^{s,s}, m_t^{y,s})), \qquad \forall t.$$

The first-order conditions are similar to those of the representative firm in the manufacturing sector and are not repeated here. Note that because of the presence of a fixed stock of capital, in equilibrium firms' profits are positive in this sector. It is worth emphasizing that p_t^s reflects the cost of producing new structures. The equilibrium price of a house differs from this value since it depends on the relative value of structures and land.

4.4 Competitive Equilibrium

The notion of competitive equilibrium is completely standard.

Competitive Equilibrium: *Given a sequence of values* $\{A_t^y, A_t^s, \theta_t\}_{t=0}^{\infty}$, *a competitive equilibrium consists of allocations* $\{c_t, x_t^k, x_t^{sh}, x_t^{sy}, l_t, n_t^y, n_t^s, m_t^{s,s}, m_t^{y,s}, m_t^{y,y}, m_t^{s,y}\}_{t=0}^{\infty}$, *and prices* $\{w_t, r_t^k, p_t^l, p_t^s, r_t, R_t\}_{t=0}^{\infty}$ *that satisfy the following:*

1. *Consumers' optimization problem,*
2. *Profit maximization in the manufacturing and construction sector,*
3. *Clearing of markets:*
   (a) *Labor markets* (w_t)
   $$n_t = n_t^y + n_t^s, \qquad \forall t,$$
   (b) *Land markets* (p_t^l)
   $$l_t = l_{t-1} = \bar{l}, \qquad \forall t,$$
   (c) *Market rental capital* (r_t^k)
   $$r_t^k = A_t^y F_1(k_t, n_t^y, m_t^{y,y}, m_t^{s,y}), \qquad \forall t,$$
   (d) *Goods markets* ($p_t^c = 1$)
   $$c_t + x_t^k + m_t^{y,y} + m_t^{y,s} = A_t^y F(k_t, n_t^y, m_t^{y,y}, m_t^{s,y}), \qquad \forall t,$$

(e) *Construction of structures* (p_t^s)

$$x_t^{sh} + x_t^{sy} + m_t^{s,s} + m_t^{s,y} = A_t^s G(n_t^s, m_t^s(m_t^{s,s}, m_t^{y,s})), \qquad \forall t.$$

We have assumed complete markets from the outset; hence this equilibrium is efficient. The details of the optimization problem solved are discussed in Appendix.

4.5 Parameterization

The quantitative evaluation of the model requires specifying parameter values and functional forms. The choice of functional forms is relatively general. The utility function is consistent with unitary income elasticity,

$$u(c, h, N) = \frac{\left[\eta c^{-\rho} + (1-\eta) h^{-\rho}\right]^{-\frac{1-\sigma}{\rho}} + \theta h}{1-\sigma},$$

where the parameter ρ pins down the elasticity of substitution between consumption, c, and housing services, h; the parameter σ represents the inter-temporal elasticity of substitution: and η represents the relative importance of consumption. The function capturing the utility from leisure is logarithmic, as is standard in the real business cycle literature with a representative agent,[13]

$$v(1-n) = \varrho \log(1-n).$$

Housing services are obtained from housing structures and land according to a Cobb-Douglas mixture,

$$h = H(s, l) = z_h (s)^{\epsilon} \left(\bar{l}\right)^{1-\epsilon},$$

where z_h represents a transformation factor between stock and flow. The production of consumption goods also uses a Cobb-Douglas technology

$$F(k, n^y, m^{y,y}, m^{s,y}) = A^y (k)^{\alpha_1} (n^y)^{\alpha_2} (m^{y,y})^{\alpha_3} (m^{s,y})^{1-\alpha_1-\alpha_2-\alpha_3},$$

where α_i represents the share in production for input i. Notice that the specification allows for substitutability between intermediate goods. The technology used in the construction sector, instead, is a CES with diminishing returns to scale,

$$G(n^s, m^{s,s}, m^{y,s}) = A^s \left[\gamma_2 (n^s)^{-\gamma_1\gamma_4} + (1-\gamma_2)\left((m^{s,s})^{\gamma_3} (m^{y,s})^{1-\gamma_3}\right)^{-\gamma_4}\right]^{-1/\gamma_4}.$$

The parameters are set to match a selected number of long-run averages in the data between 1952 and 2000. The implied values are relatively robust to the choice of the sample period;

[13] This specification implies a Frisch elasticity of labor equal to 2. Keane and Rogerson (2012) argue that this elasticity can be reconciled with lower elasticity estimates at the micro level.

however, during the housing boom some of the ratios and long-run averages departed significantly from their historical trends. Hence, to avoid stacking the cards in favor of our model, we used only data from the period before the housing boom-bust to calibrate it.

The time unit is a year, as input-output tables are yearly at best. The discount factor is $\beta = 0.96$. The depreciation rates of residential structures and nonresidential capital are $\delta^s = 0.015$ and $\delta^y = 0.115$, respectively. The weight on leisure, $\varrho = 0.33$, is such that total hours worked equal one-third of the time endowment in steady state. The preference parameters are set to match consumption-to-output and housing-to-output ratios. The parameters of the production functions are set to satisfy the following:

1. The ratio of gross output in the two sectors, $Y^s/Y^y = 0.08$
2. Average labor share in the construction sector, $= 0.7$
3. Average labor share in the manufacturing sector, $= 0.65$
4. The ratio of consumption to manufacturing gross output, $= 0.35$
5. Observed shares of intermediates in gross output of own sector (M^{sy} and M^{ys}), $= 0.4, 0.007$
6. Time allocated to market activities, $n^y + n^s = 1/3$
7. The ratio of employment in the two sectors, $n^y/n^s = 16$

The values of the parameters not mentioned above are displayed in Table 2.

The intratemporal elasticity of substitution between consumption and housing services is determined by the parameter $\varepsilon_{ch} = 1/(1 + \rho)$. Quantitatively, the value of ρ is an important determinant of the spillover effects from housing into the rest of the economy. If consumption services are close substitutes, a decline in the demand for housing services can generate an increase in the demand for the consumption good, whereas if they are close complements a decline in housing demand translates into a decline also in the demand for consumption. Various recent papers, part of an extensive literature on the topic, estimate this elasticity to be less than 1. For example, Flavin and Nakagawa (2008) uses a model of housing demand and estimate an elasticity of less than 0.2. Other papers (i.e. Kehoe et al., 2016; Song, 2010; Landvoigt, 2011) use alternative model specifications and also estimate values for the elasticity to be less than 1. The simulations consider elasticities in the range $\varepsilon_{ch} \in \{0.17, 0.25\}$.

The other key parameter is θ_t, which is used here to affect the demand for housing. We calibrate its sequence of values by means of the following procedure. Starting in 2001 the value of θ_t grows from its baseline value so that the simulated behavior of *employment* in the construction sector match the data. Each new increment is taken as a complete surprise by the decision makers. The housing boom lasts until 2007 and it is followed by the housing bust, which lasts 3 years. Thereafter, from 2010 onward, θ_t remains constant forever. The left panel in Figure 7 reports the paths for employment in the construction sector in the model and in the data. With the sequence θ_t so constructed as an exogenous input, the model is able to replicate quite well the evolution of the value added of the construction sector, as can be seen in right panel of Figure 7.

4.6 Role of Residential Investment in Growth and Employment

The goal of this exercise is to determine the dynamic behavior of all other macroeconomic quantities (output, total employment, and intermediate production) during the transition path. The baseline case considers a boom and a bust in the construction sector, which generate the total employment and aggregate value added (production of goods and construction) series summarized in Figure 8.[14] The shocks to the construction sector have non-trivial effects on total employment and value added. To evaluate the extent to which the model is capable of replicating the data dynamics, we measure the fraction of the changes in employment and GDP during the expansion period (2000-07) and during the recession (2007-10). During the boom, the exogenous changes in the demand for housing explain 60 percent of the variation in total employment and 25 percent of that in value added; during the recession the relative values are 44 percent (employment) and 56 percent (value added).[15]

In our model the exogenous crash in housing demand is represented by a sudden decrease in the demand shifter, θ_t.[16] The input-output structure of the model lowers the demand for the output of the other sector, as the demand for intermediate inputs falls. In the short run, the decline in the demand for housing generates a very small and short-lived increase in non-housing consumption; this is consistent with the empirical evidence, as can be seen in Figure 9. The temporary consumption increase, though, is not sufficient to compensate for the overall decline. In the model, the collapse of the construction sector (starting in 2007) generates a 4 percent decline in total employment and a 3.3 percent decline in aggregate value added.

Constructions lead business cycles both during both booms and during busts (see Leamer (2007)). The data also suggest that, during the booms, purchases of housing and durable goods increase faster than purchases of food and services. During the bust, the data show a very sharp decline in expenditures related to housing and durable goods, whereas non-housing related purchases continue to increase for a few more quarters. Our model captures this lead/lag patterns almost perfectly, as the two panels of Figures 9 show.

While the model predicts only a modest increase in house prices (see Garriga, Manuelli and A. Peralta-Alva (2012*b*) Garriga, Manuelli and A. Peralta-Alva (2012*a*) for a detailed discussion) it is able to capture about 40-50 percent of the decline in house prices during the bust, as shown in Figure 10.

There is abundant research arguing that a variety of different frictions affecting the labor market are important to generate significant movements in aggregate employment. Our model abstracts from such features, generating sizeable movements in employment with modest variations in wages. This is seen by comparing the top and bottom panels of Figure 10.

In our model, the complementarity between consumption and housing is an important driver

[14] The sequence of demand shifters, θ_t, is calculated to replicate the evolution of employment in the construction sector. The long-run value of θ is determined to replicate the decline in employment in the construction sector; as a result, the long-run level of employment declines relative to the initial steady state. In any event, the temporary decline in employment occurs regardless of the level of the terminal conditions. An alternative experiment would be one in which housing demand remains low for a number of periods before returning to the initial steady-state level. We have performed such experiment, and the quantitative implications are not very different. However, the long-run level of employment is higher.

[15] The magnitude of these numbers varies with the time interval considered, but the overall magnitudes are within reasonable bounds.

[16] Using the model in the Appendix, one could interpret the decline in θ_t as a tightening in the constraint in mortgage borrowing.

of the employment dynamics. To compare the model implications for different values of such complementarity we calculate, in each case, a sequence of demand shifters $\{\theta_t\}$ matching the dynamics of employment in the construction sector. The qualitative implications are the same, but the calibration with stronger complementarity generates more pronounced booms and busts. With a lower degree of complementarity, GDP falls 2 percent instead of 3.3 percent and total employment declines by 2.4 percent instead of 3.8 percent. The elasticity parameter also has implications for other variables. Figure 11 emphasizes the different lead-lag response of consumption and housing expenditure.

When the elasticity of substitution between c and h is increased from 0.16 to 0.25 consumption moves around significantly less in response to a movement in housing. In particular, when the elasticity of substitution is low consumption responds with a lag to housing, but then follows the same dynamics. As the elasticity increases, the dynamics of consumption diverges from that of housing. Increasing the elasticity to higher numbers ($\rho < 2$) would generate a boom of the consumption sector during the bust of the construction sector.

4.7 The Role of Interlinkages

In our view interlinkages have been an important driver of output and employment during the housing boom and bust. To isolate the effects of the interlinkages from those derived purely from consumers' demand for housing, we study two alternative specifications. The first uses the same parametric calibration and shuts off interlinkages by holding the sectoral demand of intermediates fixed at the level of the initial steady state, in 1998 ($m_t^{s,s} = m_0^{s,s}, m_t^{y,s} = m_0^{y,s}, m_t^{y,y} = m_0^{y,y}, m_t^{s,y} = m_0^{s,y}$). This case is referred to as "no interlinkages specification." The second formulation completely ignores the role of intermediate goods ($m_t^{s,s} = m_t^{y,s} = m_t^{y,y} = m_t^{s,y} = 0$), and the production functions are specified for value added and not gross-output.[17] In the "value-added specification", the relevant technologies are

$$c_t + x_t^k = A_t^y F(k_t, s_t^y, n_t^y),$$

and

$$x_t^{sh} + x_t^{sy} = A_t^s G(n_t^s),$$

where all the production interlinkages have been eliminated.

For both specifications we carry out the same simulation experiment under the assumption that $\rho = 5$. The time-path of the housing demand shifter is adjusted to generate movements in construction employment consistent with the data. Figure 12 compares the key macroeconomic aggregates in the three cases: baseline model, no interlinkages, and value-added only.

Consider first the case of no linkages, which is simpler. Now, the intermediates are fixed to the initial steady-state level. Both sectors are committed to produce the same amount of intermediates every period. During the housing boom, the only way to produce more structures is to use more capital and labor. Since the quantity of intermediates cannot adjust, prices become more volatile. Qualitatively speaking, the equilibrium dynamics of this version of the model are similar to those of the baseline one. However, the quantitative implications are very different.

[17] See the Appendix for model details.

Since intermediates are constant, the marginal product of labor in the construction sector does not increase as much as in the baseline experiment, and employment also does not increase as much. The construction sector expands during the boom but, because the links to the other sector have been severed, the latter barely moves in spite of the consumption complementarity: all movements are less than one-half of 1 percent. Consequently, the changes in GDP and employment are an order of magnitude smaller than in the economy with intersectoral links. The input-output links operate, de facto, as total factor productivity changes in the manufacturing sector, turning the variations in the demand for houses into a variation of the marginal value of output in the second sector.

In the value-added model, the change in the demand for housing also generates a very small boom and bust in output and employment. Here the propagation from housing to the rest of the economy travels only on the demand side, that is on the consumption complementarity, and the effect is consequently small and qualitatively different because the irreversibility constraint becomes irrelevant.

The response of consumption and housing spending is very different in each specification. In the model with fixed interlinkages, the dynamics are similar to the response in the baseline model presented in Figure 9. However, the magnitudes are significantly smaller. The dynamics of the value-added specification are very different and resemble the case of high elasticity of substitution.

The study of these three alternative specifications illustrates an important point. The presence of interlinkages is *necessary* to generate large aggregate changes from fluctuations in construction. In fact, *both* alternative models generate very small changes in output and employment (for given shifts in the demand for housing) even though both maintain the complementarity between consumption and housing in the utility function. Complementarity between housing and consumption, alone, delivers only very small aggregate fluctuations, unlike those that appear when the input-output structure of the economy is accounted for.

4.8 Quantitative Implications of Alternative Models

The different specifications we study all point to a similar conclusion: the aggregate importance of the construction sector is significant despite its relatively small share in terms of employment and value added. Table 3 presents a summary of all the results discussed above. The table shows, for each of the specifications considered, the fraction of the changes in employment and GDP accounted for by shocks to the construction sector during the expansion (2000-07) and the recession (2007-10). In light of the previous discussion the numerical values should be easy to interpret at this point. The left side of Table 3 considers the role of the construction sector in the expansion. Regardless of the complementarity between housing and consumption goods, the model with interlinkages reveals that the construction sector accounts for a very significant share of the growth in total employment: between 29 percent and 60 percent. The contribution of construction to GDP was also larger than its share— between 14 percent and 25 percent— but smaller than for employment. This could partially be due to the facts that during this period, often referred to as the "jobless recovery," most of the growth in employment was created by the construction sector.

According to the model, the contribution of construction to employment and output was arguably even more important during the Great Recession. Depending on the specification, the decline in employment generated in the models with interlinkages is between 28 percent and 44 percent of the actual decline during the recession. In the case of GDP, the model generates between 41 percent and 56 percent of the observed changes during the recession. The model suggests that construction has been an important macroeconomic driver during the housing boom-bust, and also highlights the asymmetry of its contribution between the expansion and the recession. During expansions the spillover on employment is larger than on output, but during recessions the roles are reversed.

The key role of interlinkages is also underlined by our simulations: when this channel is absent changes in the construction sector have much smaller macroeconomic effects on aggregate output and employment. This is the case even when consumption and housing are more complementary than the conventional macro model assumes, e.g. Iacoviello (2005).

5 Interlinkages and Business Cycle Accounting

An alternative methodology to identify the sources of economic fluctuations, within the context of a one-sector growth model, is "business cycle accounting", and it is based on Chari et al. (2007). Recent works, including Arellano et al. (2010) and Ohanian and Raffo (2012), document that the Great Recession can mostly be accounted for by a worsening of labor market distortions. Both studies cited find that the labor wedge worsens by about 12 percent during the 2009 recession. Different explanations have been proposed to rationalize the measured increase in distortions in the labor market. For instance, Arellano et al. (2010) propose a model of imperfect financial markets and firm-level volatility. Such model captures about half of the worsening in the labor wedge.

The wedge can be computed using data on employment, consumption, and wages generated by any model. It is defined as

$$X_t = -\frac{U_{N_t}}{U_{C_t}}/w_t,$$

where U_{N_t} is the marginal disutility measured at the aggregate level of employment, U_{C_t} is the marginal utility of consumption measured at the aggregate level of consumption, and w_t is the aggregate wage rate. Assuming wages are flexible and considering an aggregate Cobb-Douglas production function with capital share α, the wage can be replaced with

$$w_t = \frac{Y_t}{N}(1-\alpha).$$

Furthermore, using a log utility function for consumption and the following function for the disutility of employment,

$$U(N) = B\frac{N}{1+\upsilon}^{1+\upsilon},$$

the wedge can be written as

$$\Gamma_t = -\frac{B}{(1-\alpha)}\frac{C_t}{Y_t}N_t^{1+\upsilon}.$$

Notice that the parameters B and α are not important to understand fluctuations in the labor wedge; only the time series of aggregate consumption, output, and employment, and a value for υ, are required. We consider three values of $\upsilon = \{0.5, 1, 2\}$ and compute the labor wedge implied by our model using simulated data for consumption, output, and employment. Since our model has multiple sectors, several adjustments in the data are necessary. Consumption of goods and housing services are aggregated using relative prices $C_t = c_t + R_t h_t$. Aggregate output is $Y_t = C_t + X_t^k$ and total employment is $N_t = n_t^y + n_t^s$.

In the context of our model, any action in terms of implied distortions must be derived from the input-output structure and changes in relative prices. Figure 12 displays the changes in the labor wedge for our benchmark simulation. The behavior is consistent with the data. The labor wedge worsens during the recession and does not recover quickly. For the case computed with $\upsilon = 1$, which is consistent with the value used by Ohanian and Raffo (2012), the labor wedge worsens by 7.4 percent; this is about 62 percent of the total change in the labor wedge during this period. Notice that our computation of the labor wedge assumes that wages are perfectly flexible. If this condition does not hold, the labor wedge has another component, referred to as the "firm-side" labor wedge in Arellano et al. (2010).[18] This wedge is basically the difference between the marginal product of labor and the wage. These authors refer to the other component of the labor wedge as the "consumer-side" labor wage, which is basically our Γ_t. Arellano et al. (2010) find that (i) the firm-side labor wedge has been fairly flat since 2006 and (ii) a worsening of the consumer-side labor wedge accounts for most of the Great Recession. Recall that there are no frictions in our model, so wages equal the marginal product of labor in every period. Thus, not only the behavior of the labor wedge during the Great Recession but also its decomposition in the data are consistent with what our model predicts. It can also be shown that our model would be consistent with a large and fairly persistent negative shock to total factor productivity. The combination of these two would rationalize the model predicted Great Recession.

6 Conclusions

This paper analyzes the contribution of the construction sector to U.S. economic growth, particularly during the Great Recession. Historically, the construction sector has been relatively small in terms of employment and contribution to GDP, but it is highly interconnected with other sectors in the economy and also highly volatile. Our empirical analysis reveals how these sectoral interlinkages propagate changes in housing demand, greatly amplifying their effect on the overall economy. Simple input-output accounting reveals that construction accounts for 52 percent of the decline in employment, and 35 percent of the decline in output, during the Great Recession and for similar, albeit slightly smaller, shares during the preceding boom.

The importance of the sectoral interlinkages is illustrated first using a simple static multisector model. We prove that, in our model, changes in housing demand have a much larger effect on aggregate activity when the sectors are interconnected. Also, the presence of irreversibility constraints on investment introduces an asymmetry between the expansion and the recession in the dynamic model. The simulation exercise is calibrated to reproduce the boom-bust dynamics of employment in construction during the period 2002-10. During the housing boom the model predicts, respectively, a 2 percent and a 2.5 percent increase in aggregate output

[18] They follow Galí et al. (2007) in this decomposition.

and employment. During the housing bust the decline in aggregate output is 3.3 percent while that in employment is 3.8 percent. Because during a recession the irreversibility constraint on investment does bind, the aggregate response to the housing shock is amplified. With a lower degree of complementarity in the utility function the asymmetric effect is not as large but still significant.

In terms of the share of total variations, our model suggests that during the expansion (2002-07), the construction sector accounted for a significant share of the growth in employment (between 29 and 60 percent) and GDP (between 14 and 25 percent). The construction sector's contribution was even larger during the Great Recession (2007-10): our model says that movements in housing demand, propagating through the economy, accounted for variations of aggregate employment in the 29-44 percent range and of GDP in the 41-56 percent range.

The presence of intersectoral linkages substantially amplifies the impact of changes in housing demand. In the specifications without interlinkages, changes in housing demand consistent with the dynamics in construction employment have only a small effect on macroeconomic quantities. This is true even when the complementarity between consumption goods and housing services is high. A direct implication of this result is that the presence of interlinkages is *necessary* to generate large aggregate variations from changes in construction, and a high degree of complementarity is not *sufficient* to obtain the propagation of adjustments in housing demand to the rest of the economy we obtain in our model. To capture the intricacies of this mechanism it is necessary to formalize the aggregate economy with a multi-sector model with asymmetric interlinkages.

Since in our model the equilibrium is efficient, the behavior of output is also the behavior of potential output. Taking into account that both output and potential output were affected during the Great Recession, we perform a business cycle accounting exercise on simulated data from the model using the now common "wedges" approach. Despite the lack of any frictions or distortions in our model, the data it generates attribute the recession to a worsening of the labor wedge. The magnitude generated by the model accounts for 62 percent of the total change observed in the data. Clearly, in the case of our model, what the metrics of the "wedges" measures is a combination of sectoral linkages, irreversibilities and movements of relative prices across sectors, not frictions. This shows how multisector models of the business cycle can improve, or at least change, our understanding of the factors driving aggregate fluctuations.

A direct policy implication of our findings is that the output gap could be lower than historical estimates suggest. The historical anomalies in the events that took place between 2007 and 2013 can be accounted for by the equally anomalous evolution of housing demand in the six years previous to 2007 and in those following it. As far as policy is concerned, the basic implication of our research is simple: estimations of output gaps using pre-2007 trends, and aggregate one-sector models, may lead to misleading policy prescriptions.

This model abstracts from sizable income and wealth effects due to deleveraging and mortgages. This is a limitation, which we accepted in the face of computational constraints. As a result, all short-run dynamics are driven entirely by substitution effects. The interaction between the financial factors used in Garriga, Manuelli and A. Peralta-Alva (2012*b*), Garriga, Manuelli and A. Peralta-Alva (2012*a*) with the production structure of the paper should magnify the importance of the sectoral interlinkages. The inclusion of wealth effects and frictions from housing finance should also be a natural extension.

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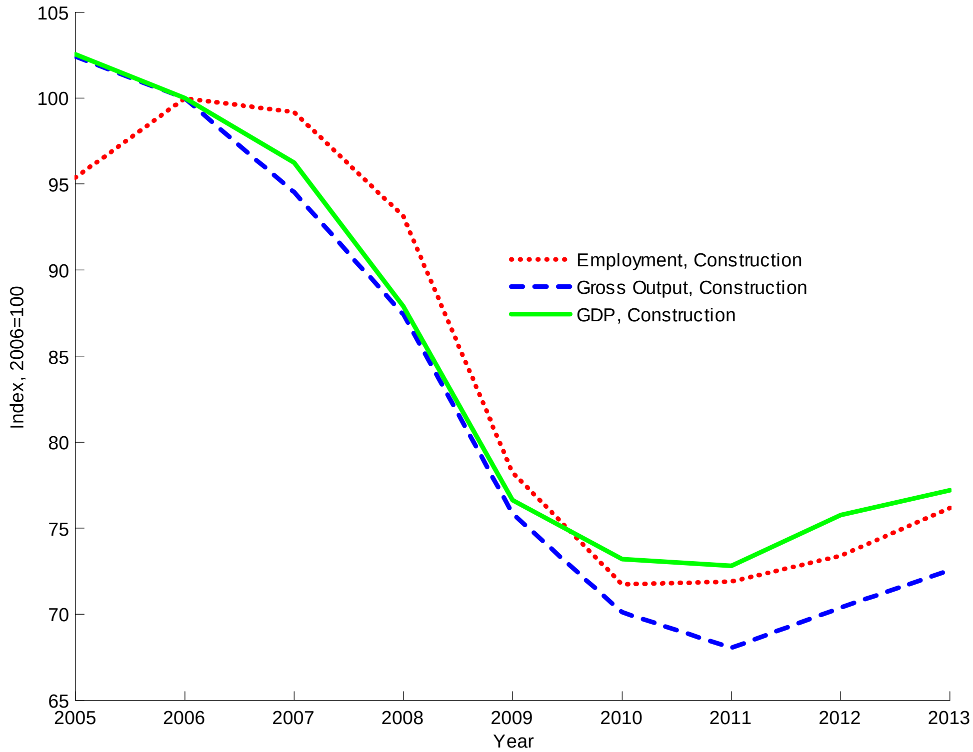
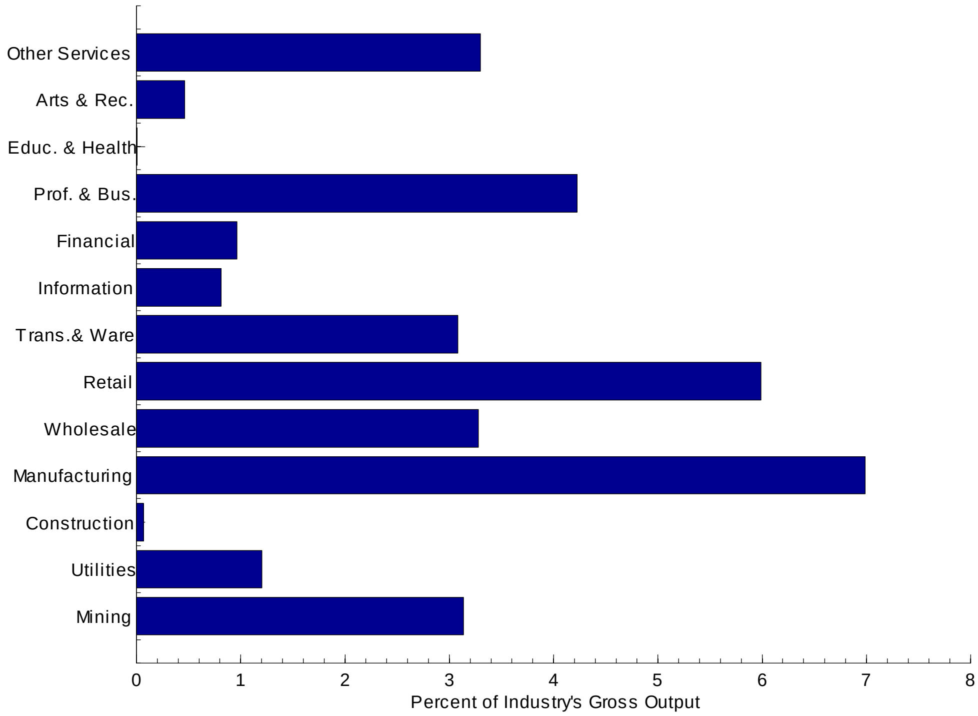
Figure 1: The Construction Sector during the Great Recession



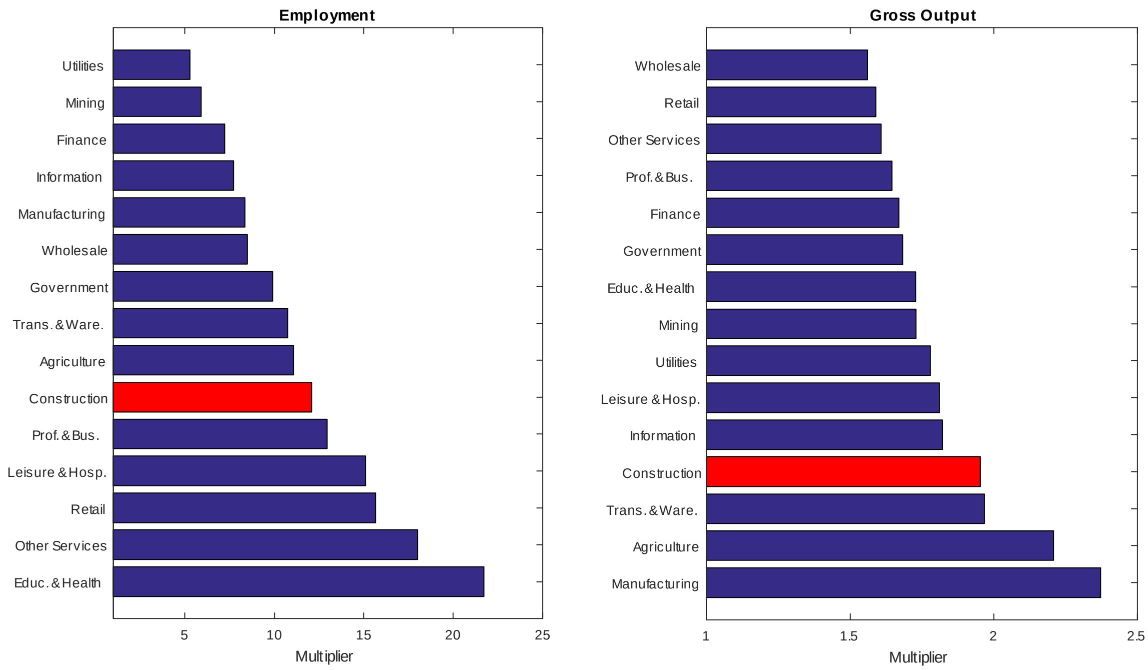
Source: BEA.

Figure 2: Purchases from Other Sectors



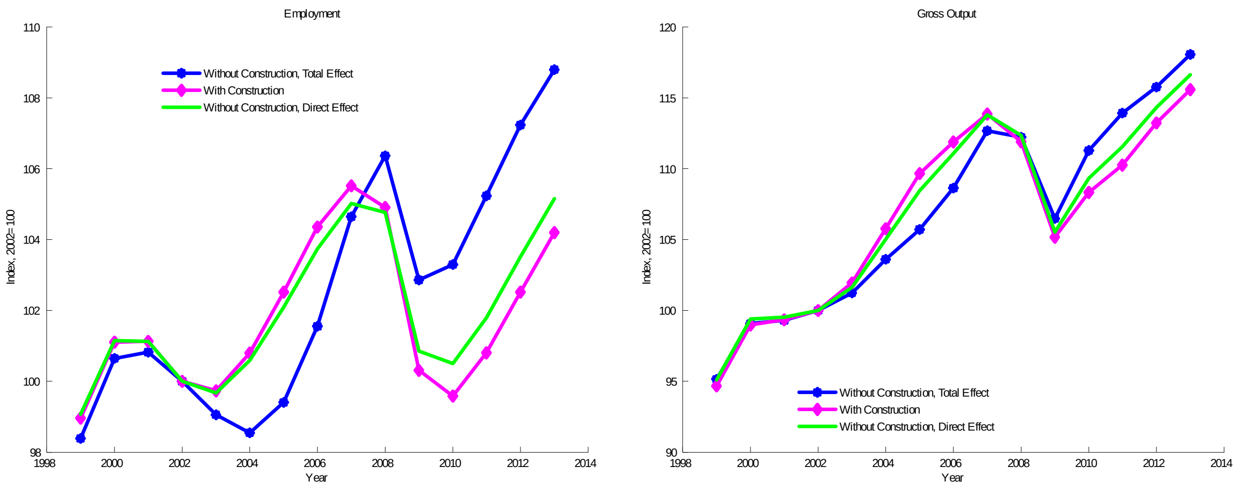
Source: 2006 Use matrix from the BEA input-output tables.

Figure 3: Sectors' Multipliers



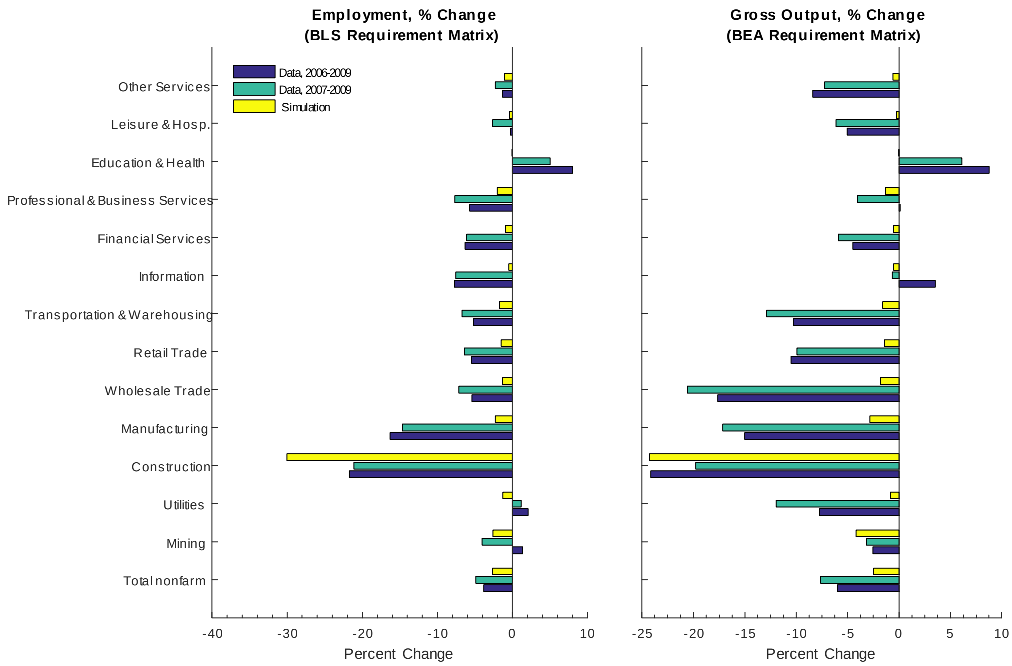
Source: 2006 Use matrix from the BEA and BLS input-output tables.

Figure 4: Construction Sector's Contribution to the Dynamics of Employment and Gross Output



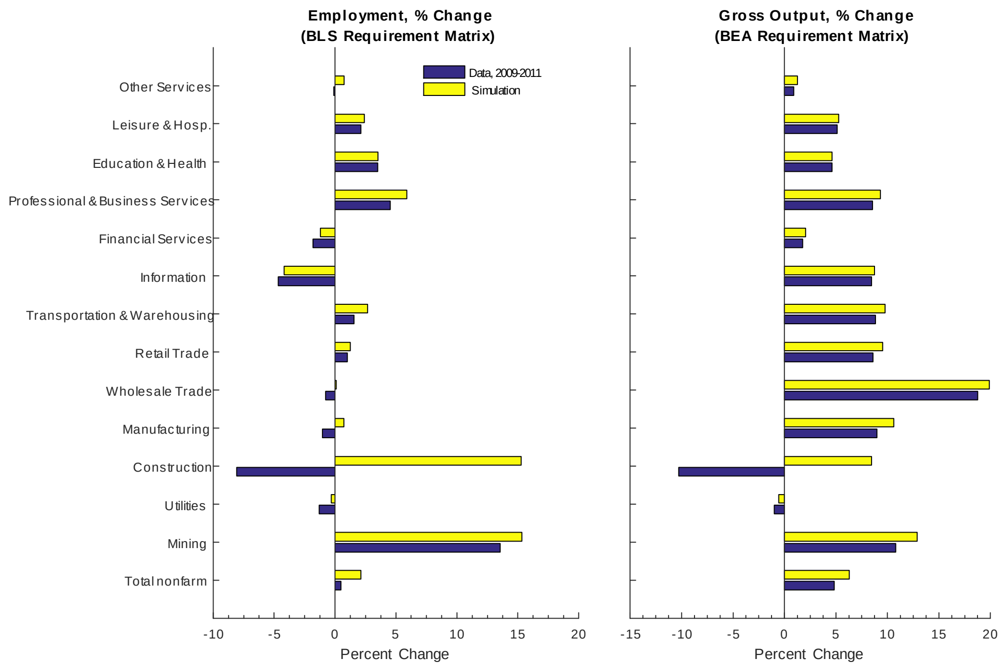
Source: Authors' calculations using Bureau of Economic Analysis (BEA) and Bureau of Labor Statistics (BLS) Requirement Tables.

Figure 5: Sectoral changes during the Great Recession (Data and Input-Output Simulations)



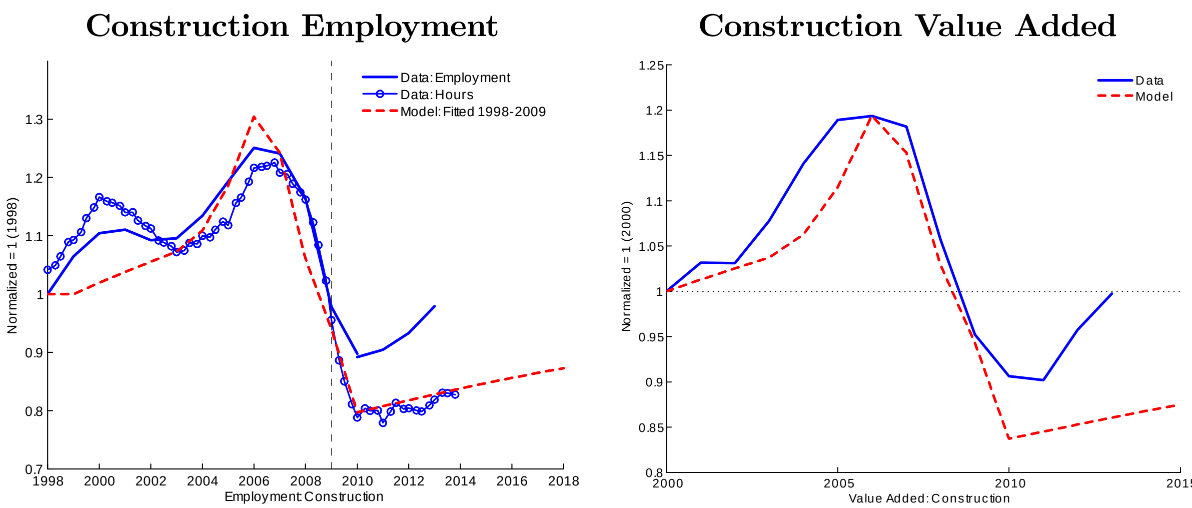
Source: Authors' calculations using BEA data.

Figure 6: Sectoral changes during the Recovery (Data and Input-Output Simulations)



Source: Authors' calculations using BEA data.

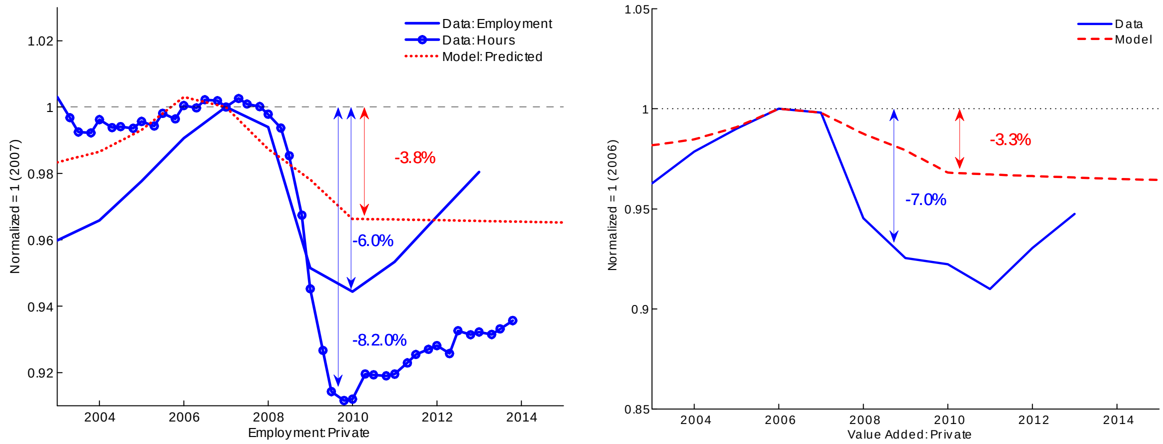
Figure 7: Dynamics of the Construction Sector (Model and Data)



Source: Bureau of Economic Analysis and Authors calculations

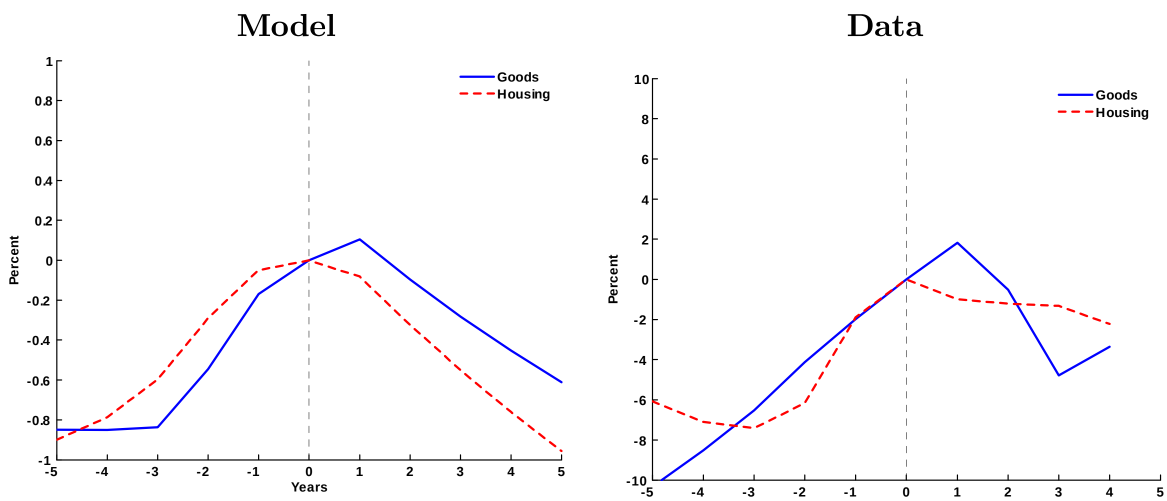
Figure 8: The Aggregate Implications of Construction

Total Employment | **Aggregate Value Added (GDP)**



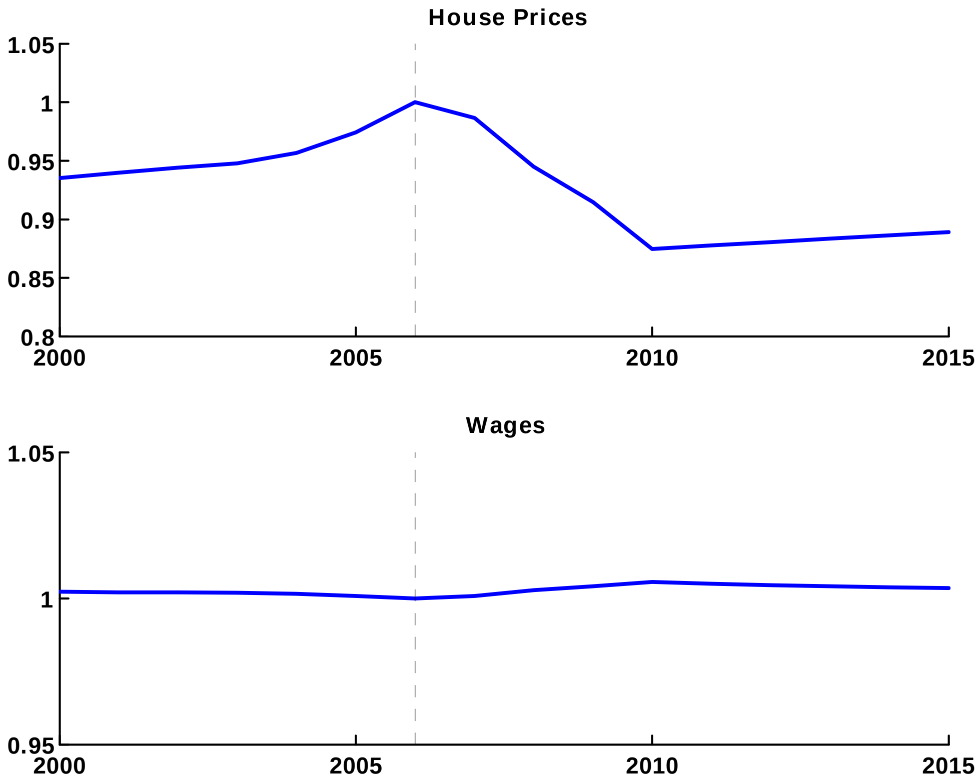
Source: Bureau of Economic Analysis and Authors' calculations

Figure 9: Lead-Lag Response of Consumption and Housing Spending



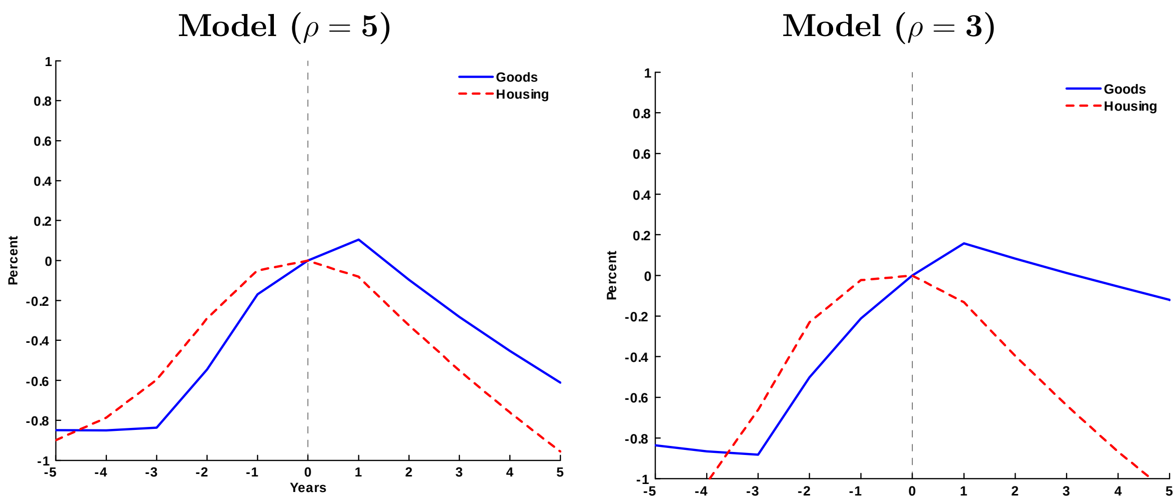
Source: Bureau of Economic Analysis and Authors calculations

Figure 10: House Prices and Wages



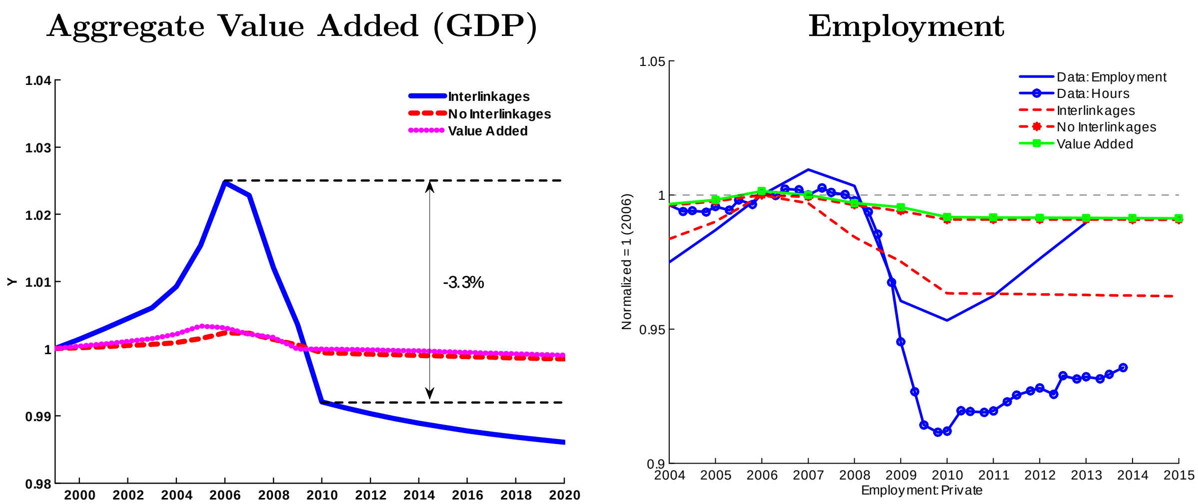
Source: Authors' calculations

Figure 11: Lead-Lag Response of Consumption and Housing Spending



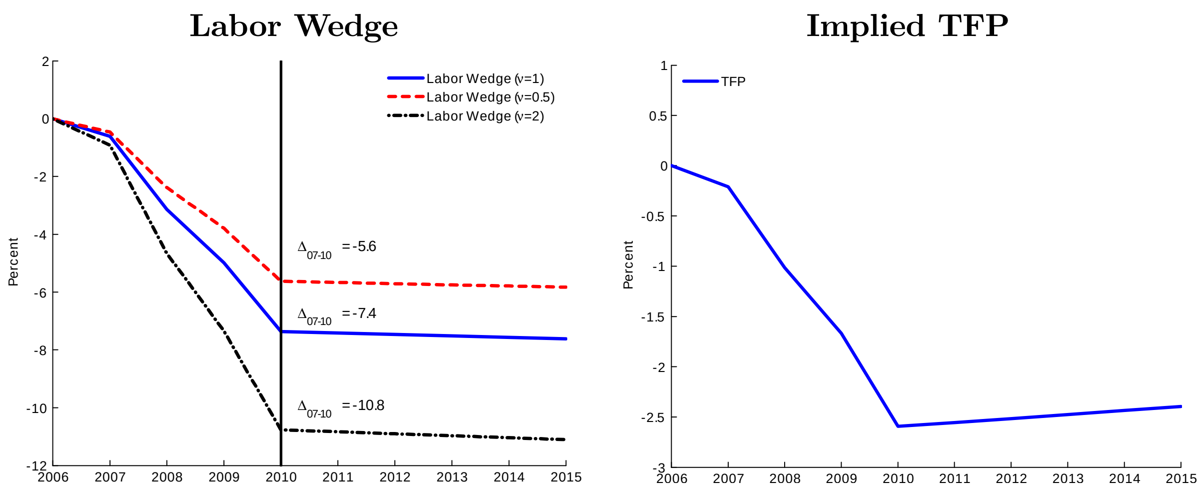
Source: Authors calculations

Figure 12: The Impact of Construction: Role of Interlinkages ($\rho = 5$)



Source: Bureau of Economic Analysis and Authors calculations

Figure 13: The Business Cycle Accounting of the Model with Interlinkages



Source: Bureau of Economic Analysis and Authors' calculations

Table 1: **The role of construction in the last three recessions**

	Employment		Real Income ($)	
Recessions	Construction	Priv. Total	Construction	Priv. Total
1990-91				
Peak, 1990Q3 (millions)	5.24	109.6	346.0	7455
Trough 1991Q1 (millions)	4.93	108.7	320.6	7400
Difference (millions)	-0.31	-0.87	-25.4	-54.9
% accounted by construction	35.4		46.3	
2000-01				
Peak 2000Q1 (millions)	6.84	132.6	610.4	10870
Trough 2001Q4 (millions)	6.79	131.0	598.7	10629
Difference (millions)	-0.05	-1.55	-11.70	-241.1
% accounted by construction	3.3		4.9	
2007-09				
Peak 2007Q4 (millions)	7.53	137.9	682.3	12586
Trough 2009Q2 (millions)	6.09	131.0	540.5	11852
Difference (millions)	-1.4	-6.9	-141.8	-734.0
% accounted by construction	20.8		19.3	

Source: Bureau of Economic Analysis (BEA) and Bureau of Labor Statistics (BLS).

Table 2

Parameter Values

Parameter	α_1	α_2	α_3	γ_1	γ_2	γ_3	γ_4	A^y	A^s	z_h	ϵ	η	σ	ρ
Value	0.18	0.5	0.035	0.62	0.4	0.04	1.5	2.4	1.74	0.175	0.28	0.435	1	5

Table 3

Quantitative Implications of Alternative Models

	Share of changes accounted for by the construction sector			
	Expansion 2000-07		Recession 2007-10	
Experiment	Employment (%)	GDP (%)	Employment (%)	GDP (%)
Baseline ($\rho = 5$)	60.2	25.3	43.9	56.2
Lower complementarity ($\rho = 3$)	28.7	14.1	28.7	40.6
Value-added specific. ($\rho = 5$)	14.9	3.2	14.5	8.5
No Interlinkages Specific. ($\rho = 5$)	14.5	2.5	10.6	4.8

Source: Authors' calculations

7 Appendix

7.1 Microfoundations for the Housing Demand Shifters

The modeling strategy used in the paper uses changes in "effective" housing demand as the driver of the amplification mechanism through sectorial interlinkages. There are many potential drivers of the changes in housing demand during this experience. This particular episode witnessed sizeable changes in home ownership and significant innovations in housing finance at the household level (i.e., new mortgage products) and the industry level (i.e., the use of mortgage backed securities as a liquid asset). This subsection provides a microfoundation of housing demand shocks using two different specifications. The first one uses credit constraints in housing finance, where changes in collateral requirements (i.e., loan-to-value ratio) are isomorphic to variations in the relative weight of housing in preferences (intensive margin). The second one considers the case where a large number of households enter in the owner-occupied housing market but purchase the same size house. At the aggregate level this is also captured as an increase in the aggregate demand for housing (extensive margin). Either specification would be consistent with the approach used by Chari et al. (2007) that reduces all the frictions in the model to distortions/wedges in the equilibrium conditions.

7.1.1 "Effective" Housing Demand and Credit Constraints

The first specification related housing demand to the presence of credit constraints. Consider a simple two-period extension of the household optimization problem to allow for borrowing and collateral constraints of the form $b \leq \lambda ph$. This is the standard constraint that restricts the amount of housing finance to be proportional to the value of the house, $\lambda \in [0, 1]$. The cost of borrowing, $R > 1$, is paid in the second period and can differ from the return of other assets, r.[19] For ease of exposition consider the case where housing fully depreciates at the end of the second period, and labor is inelastically supplied. The optimization problem of the representative consumer is

$$
\begin{aligned}
\max_{c_1, c_2, h, s, b} \; & u(c_1) + \beta u(c_2) + \tilde{\theta} v(h), \\
s.t. \quad & c_1 + s + ph = w_1 + b, \\
& b \leq \lambda ph, \\
& c_2 = w_2 + (1 + r)s + bR.
\end{aligned}
$$

The optimality condition for housing measured in terms of $t = 1$ consumption goods can be

[19] In this class of model, the consumer usually has an incentive to borrow to purchase the house when the cost of borrowing is lower than the return of other assets, $R/1 + r = \phi < 1$ (additional conditions are discuss below). In many countries, interest payments are tax deductible reducing the effective cost of borrowing relative to other assets. Under this assumption, the Lagrange multiplier of the collateral constraint binds, and housing demand directly determines the amount of borrowing.

written as[20]

$$\theta \frac{v'(h)}{u'(c_1)} = p[1 - \lambda(1+\phi)].$$

When the solution is interior, increases in the value of λ reduce the cost of housing relative to consumption goods. This is observationally equivalent to an exogenous increase in θ. Similarly, a tightening of credit conditions reduces housing demand. From this perspective, the relevant value is $\tilde{\theta} = \theta/[1 - \lambda(1+\phi)]$. When housing finance is not presence, $\lambda = 0$, the expression for housing demand is the same as in the previous model, and $\tilde{\theta} = \theta$.

7.1.2 "Effective" Housing Demand and Home ownership

Part of the housing boom was fueled by an increase in the home ownership rate.[21] The second specification relates the aggregate change in housing demand to an increasing participation in the housing market using a model based on Garriga, Chambers and Schlagenhauf (2012). To highlight the aggregate effect of this channel, the model considers an indivisible housing good. Consider an economy where households are ex-ante heterogeneous in their labor ability $\varepsilon \in [\underline{\varepsilon}, \overline{\varepsilon}]$, where the ability distribution is uniform $\varepsilon \tilde{} U(\underline{\varepsilon}, \overline{\varepsilon}) \equiv f(\varepsilon)$. Preferences are represented by a utility function $u(c,h) = c(\theta + h)$, where consumption goods are perfectly divisible, $c \in R_+$, and housing is a discrete good with only one size of home available, $h \in \{0, \overline{h}\}$. The implicit assumption is that renters consume zero housing and homeowners consume a positive amount. The model could allow for the purchases of different size homes at the cost of introducing unnecessary notation. The parameter $\theta > 0$ can be interpreted as a reservation value for rental housing, and as $\theta \to 0$, owner-occupied housing is more desirable.

The optimization problem for the consumer is

$$\begin{aligned} v(\varepsilon) &= \max_h \{u^r(c^r, 0), u^o(c^o, \overline{h}), \\ s.t. \qquad c^o &= w\varepsilon - (p\overline{h} + \phi), \\ c^r &= w\varepsilon, \end{aligned}$$

where w represents the income from wages, p is the house price, and the price of consumption goods is been normalized to one. The term ϕ represents an exogenous transaction cost associated to buying a house measured in terms of consumption goods. The optimal decision rule determines a cut-off level of ability necessary to purchase owner-occupied housing. For the specified preferences and under the necessary assumptions for an interior solution, the threshold of homeownership, ε^*, is characterized by

$$\varepsilon^*(\gamma, \overline{h}, \phi, p, w) \geq \frac{p}{w}(\theta + \overline{h}) + \frac{\phi}{w\overline{h}}.$$

In the model, the determinants of ownership are the cost of housing relative to income, p/w,

[20] For an interior solution with borrowing it suffices that, $\lambda < 1/(1+\phi)$.

[21] See Chambers et al. (2009*a*), Chambers et al. (2009*b*) for a detailed discussion on the home ownership rate boom between 1994 and 2007.

the minimum size available, $\overline{h}$, transaction costs, ϕ, and the reservation value of rental housing, θ.[22] The comparative statics are straight forward. Increases in house prices, minimum size, and transaction costs increase the income threshold required form home ownership whereas an increase in wage income decreases it. Notice that the demand shifter does not change the size of housing purchased by each individual but the number of individuals buying homes.

Given the indivisible nature of housing, aggregate housing demand and the home ownership rate proportional

$$H(p) = \overline{h} \int_{\varepsilon^*}^{\overline{\varepsilon}} U(\underline{\varepsilon}, \overline{\varepsilon}) d\varepsilon = \frac{\overline{h}}{(\overline{\varepsilon} - \underline{\varepsilon})} \left[\overline{\varepsilon} - \frac{p}{w}(\theta + \overline{h}) - \frac{\phi}{w\overline{h}} \right].$$

Despite the simplicity, the expression shows the connection between housing demand and the key individual variables. A reduction in the rental threshold, θ, affects the total quantity demanded to the construction sector, but also a reduction in the transaction costs, ϕ, affect housing demand.

7.2 Alternative Specifications Quantitative Model: Fixed Interlinkages and Value Added Economies

In the quantitative analysis it is important to disentangle the role of interlinkages. It is always challenging to compare different models, but the quantitative analysis suggests similar results from the various alternatives. The first alternative considers an economy calibrated to the same initial steady state (parameters and targets) and compares the economy with interlinked production with an economy that fixed the size of intermediates to the initial steady-state levels. The second alternative compares the value-added economy with the economy with interlinkages. Both economies are calibrated to the same target values for the baseline year, but the underlying parameters are different.

There is an optimization problem that solves for the equilibrium in each case. Those cases are presented here with a slightly more general assumption: The production function F also uses structures, referred to as s_t^y. The structures used for the production of housing services are now referred to as s_t^h instead of just s_t.

In the baseline case with interlinkages, the social planner problem chooses a sequence of quantities $\{c_t, x_t^k, x_t^{sh}, x_t^{sy}, l_t, n_t^y, n_t^s, m_t^{s,s}, m_t^{y,s}, m_t^{y,y}, m_t^{s,y}\}_{t=0}^{\infty}$ to maximize

$$\max \textstyle\sum_{t=0}^{\infty} \beta^t [u(c_t, \theta_t, h_t) + \gamma v(1 - n_t^y - n_t^s,)],$$

[22] When the transaction cost is proportional to the value of the house. The budget constraint of the buyer is slightly different $c^o = w\varepsilon - (p + \phi)\overline{h}$ and the homeownership threshold is $\varepsilon^* \geq \frac{(p+\phi)}{w}(\theta + \overline{h})$.

$$
\begin{aligned}
s.t. \qquad c_t + x_t^k + m_t^{y,y} + m_t^{y,s} &= A_t^y F(k_t, s_t^y, n_t^y, m_t^{y,y}, m_t^{s,y}), \qquad \forall t,\\
x_t^{sh} + x_t^{sy} + m_t^{s,s} + m_t^{s,y} &= A_t^s G(n_t^s, m_t^s(m_t^{s,s}, m_t^{y,s})), \qquad \forall t,\\
x_t^k &= k_{t+1} - (1-\delta_k)k_t \geq 0, \qquad \forall t,\\
x_t^{sh} &= s_{t+1}^h - (1-\delta_{sh})s_t^h \geq 0, \qquad \forall t,\\
x_t^{sy} &= s_{t+1}^y - (1-\delta_{sy})s_t^y \geq 0, \qquad \forall t,\\
h_t &= H(s_t^h, \bar{l}), \qquad \forall t,\\
& s_0, l_0, k_0 \geq 0.
\end{aligned}
$$

In the model with no interlinkages, the production of intermediate goods is fixed to the initial steady-state levels before the housing boom. In this case, the social planner is forced to produce the same quantity of intermediates each period ($m_t^{s,s} = m_0^{s,s}, m_t^{y,s} = m_0^{y,s}, m_t^{y,y} = m_0^{y,y}, m_t^{s,y} = m_0^{s,y}$). To satisfy the production of the intermediate goods, the social planner can choose a constrained vector of quantities $\{c_t, x_t^k, x_t^{sh}, x_t^{sy}, l_t, n_t^y, n_t^s\}_{t=0}^{\infty}$ to maximize

$$
\max \textstyle\sum_{t=0}^{\infty} \beta^t [u(c_t, \theta_t h_t) + \gamma v(1 - n_t^y - n_t^s,)],
$$

$$
\begin{aligned}
s.t. \qquad c_t + x_t^k &= A_t^y F(k_t, s_t^y, n_t^y, m_0^{y,y}, m_0^{s,y}) - (m_0^{y,y} + m_0^{y,s}), \qquad \forall t,\\
x_t^{sh} + x_t^{sy} &= A_t^s G(n_t^s, m_0^s(m_0^{s,s}, m_0^{y,s})) - (m_0^{s,s} + m_0^{s,y}), \qquad \forall t,\\
x_t^k &= k_{t+1} - (1-\delta_k)k_t \geq 0, \qquad \forall t,\\
x_t^{sh} &= s_{t+1}^h - (1-\delta_{sh})s_t^h \geq 0, \qquad \forall t,\\
x_t^{sy} &= s_{t+1}^y - (1-\delta_{sy})s_t^y \geq 0, \qquad \forall t,\\
h_t &= H(s_t^h, \bar{l}), \qquad \forall t,\\
& s_0, l_0, k_0, m_0^{s,s}, m_0^{y,s}, m_0^{y,y}, m_0^{s,y} \geq 0,
\end{aligned}
$$

The formulation considers the value-added economy where the intermediate goods have been completely eliminated. The social planner chooses a vector of quantities $\{c_t, x_t^k, x_t^{sh}, x_t^{sy}, l_t, n_t^y, n_t^s\}_{t=0}^{\infty}$ to maximize

$$
\max \textstyle\sum_{t=0}^{\infty} \beta^t [u(c_t, \theta_t h_t) + \gamma v(1 - n_t^y - n_t^s,)],
$$

$$
\begin{aligned}
s.t. \qquad c_t + x_t^k &= A_t^y F(k_t, s_t^y, n_t^y), \qquad \forall t,\\
x_t^{sh} + x_t^{sy} &= A_t^s G(n_t^s), \qquad \forall t,\\
x_t^k &= k_{t+1} - (1-\delta_k)k_t \geq 0, \qquad \forall t,\\
x_t^{sh} &= s_{t+1}^h - (1-\delta_{sh})s_t^h \geq 0, \qquad \forall t,\\
x_t^{sy} &= s_{t+1}^y - (1-\delta_{sy})s_t^y \geq 0, \qquad \forall t,\\
h_t &= H(s_t^h, \bar{l}), \qquad \forall t,\\
& s_0, l_0, k_0 \geq 0,
\end{aligned}
$$

where the presence of intermediate inputs has been completely eliminated.

7.3 Calibration of Interlinkages

Interlinkages are calibrated using input-output data. In particular, the information shown in Table A1 is used to calibrate the parameters in the production function of consumption goods and residential structures. In particular, the tables are constructed from the 2010 BEA's Use input-output table. The Use table shows the uses of commodities by intermediate and final users; rows present the commodities or products, and columns display the industries and final users that use them. The sum of the entries in a row is the output of that commodity. The columns show the products consumed by each industry and the three components of "value added"—compensation of employees, taxes on production and imports less subsidies, and gross operating surplus. Value added is the difference between an industry's output and the cost of its intermediate inputs, and total value added is equal to GDP.

Table A1 displays input-output values (which are originally in millions of dollars) as a fraction of the industries' outputs. Construction receives most of its inputs from other industries (48.3 percent of its gross output) and less than 1 percent from itself. This is also true for other industries since they receive most of their inputs from themselves (43.0 percent of their total gross output).

Table A1: Coefficients with Respect to Column Industries

Commodities/Industries	Construction	Other Industries
Construction	0.0009	0.0058
Other industries	0.4828	0.4301
Compensation of employees	0.3625	0.2802
Taxes on production and imports, less subsidies	0.0072	0.0471
Gross operating surplus	0.1466	0.2368
Total	1.0000	1.0000

Source: Use input-output table (BEA).