

# Homework in Monetary Economics: Inflation, Home Production, and the Production of Homes\*

S. Borağan Aruoba

University of Maryland

Morris A. Davis

University of Wisconsin - Madison

Randall Wright

University of Wisconsin - Madison

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## Abstract

We study the effects of inflation in a monetary model extended to incorporate both household production and endogenous investment in housing. As long as cash is used in market transactions, inflation is a tax on market activity, but not on home production. Inflation thus causes substitution out of market and into household activity, encouraging investment in household capital, including housing. We show analytically that through this channel, inflation increases the value of housing scaled by either nominal output or the money supply. We document these relationships in the data, and investigate how a calibrated model can account for the facts.

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# 1 Introduction

It is often heard that housing may be a good hedge against inflation. Is this true? And, if so, why? In this paper we first document that this is indeed the case using four different data source for the U.S. and also for 16 advanced economies. Our empirical analysis makes a very strong case that house values (scaled appropriately) and inflation are positively related.

While one may be able to think of alternative ways to address this empirical fact, we pursue the following idea. First, inflation is a tax on market activity. This is so because inflation leads directly to a reduction in the value of one's money holdings, including currency, but also including demand deposits, and perhaps other liquid assets, at least to the extent that nominal returns on these assets do not adjust perfectly to inflation (which we think is true of currency, for sure, and demand deposits to a great extent). Second, a tax on market activity leads agents to substitute out of this and into nonmarket activity, and in particular into household production – e.g., one may eat out less and cook at home more when market activity is taxed. Inflation is a tax on market activity, to the extent that at least some of this activity uses cash; it is not a tax on household production since, by definition, home-produced goods are not even traded on the market, let alone traded using cash.

When inflation is higher, at the margin, naturally people move into relatively more into household production activity. This means an increase in the inputs to the household production function, including time and capital. Home capital includes home appliances, and also the house itself. Hence, inflation leads to an increase in the demand for housing. This increases value of the housing stock, perhaps mostly through the price in the short run, when supply is relatively fixed, and through quantity in the longer run, as supply adjusts, though it cannot fully adjust since land is a fixed factor. In this way we think there is an interesting link between home production and the production of homes. The main novelty in our story is to recognize the impact of inflation on the housing market, providing a new

perspective on the old idea that, as an asset, housing is a good hedge against inflation. To this end, we integrate the literature that attempts to take the microfoundations of monetary exchange seriously (in order to be able to talk about the real effects of inflation) with the literature incorporating household production into macroeconomics, as well as the literature that models housing explicitly.<sup>1</sup>

It has already been documented that incorporating household production into otherwise standard macro models can have significant effects. Early examples showing this in the context of business cycle analysis include Benhabib et al. (1991) and Greenwood and Hercowitz (1991). Roughly speaking, these models put some of the ideas of Becker (1965, 1988) into dynamic general equilibrium theory. Models with household production do a better job than similar models without household production in terms of matching many business cycle observations. It has also been shown that they allow us to account better for consumption (Baxter and Jermann 1999, Baxter 2010, Aguiar and Hurst 2005, 2007*a*), investment (Gomme et al. 2001, Fisher 1997, 2007), female labor-force participation (Greenwood et al. 2005, House et al. 2008, Albanesi and Olivetti, 2009), and labor supply in general, including retirement and other life-cycle aspects (Rios-Rull 1993, Rupert et al. 2000, Gomme et al. 2004, Aguiar and Hurst 2007*b*, Ngai and Pissarides 2008, Rogerson and Wallenius 2009). They also give different answers to important policy questions, such as the impact of income taxation (McGrattan et al. 1997, Rogerson 2009). They also do a better job accounting for international differences in income per capita, providing a different perspective on growth and development issues (Einarsson and Marquis 1997, Parente et al. 2000).

In this paper we consider whether household production may be a potentially important and previously neglected ingredient in monetary economics. The basic structure follows

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<sup>1</sup>For recent surveys of the microfounded monetary economics that we have in mind, sometimes referred to as New Monetarist Economics, see Nosal and Rocheteau (2011) or Williamson and Wright (2010*a,b*). On home production, which goes back to Becker (1965), see surveys by Greenwood et al. (1995) and Gronau (1997), although we explicitly review many of the contributions below. We also review the related literature on housing, but as a preview, the basic structure follows Davis and Heathcoate (2005).

Aruoba et al. (2011), which is a generalization (to include capital, fiscal policy and several other standard macroeconomic ingredients) and an attempt to quantify the monetary theory in Lagos and Wright (2005). Here we further extend that framework to include household production, where housing is produced using land and structures, and is used as an input in the production of home consumption goods. Thus housing, as nonmarket capital, is valued for its role as an input in home production, just like market capital is valued as an input in market production in standard macro. The model is used to analyze qualitatively and quantitatively the effect of monetary policy, in terms of anticipated inflation, through the channel described above. As an example of a specific application, we measure how much of the relationship between monetary policy and relative house values in the US data can be generated by our mechanism, abstracting (as in any controlled experiment) from other potentially relevant factors.<sup>2</sup>

In terms of the other related literature, many papers (see, e.g., Geromichalos et al. 2007 for references) study the relation between the stock market and inflation, which is similar in the sense that it asks how monetary policy affects asset prices, and as we said, for us a house is an asset. But a house is different from a generic asset, for several reasons. For one, dividends on financial asset are outside any individual investor's control, while housing, as an input to household production, is more directly under a household's control. For another, payoffs on assets enter typical economic models via the budget equation; the payoff on a house also enters through the utility function. Few authors have focused squarely on the relationship between housing prices and inflation the way we do. Some papers study the effects of

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<sup>2</sup>In spirit, although the models are very different, this experiment is related to the exercise in Berentsen et al (2011), where it is asked how much of the observed rise in unemployment over roughly the same period can be generated by purely by inflation. We think the framework has many other potential applications. As an example, the model can be used to measure the effect of inflation on welfare. It is by now well known that modeling monetary economies explicitly – i.e., with some attempt to think seriously about microfoundations – generates different answers to questions concerning the cost of inflation. It is also generally understood that incorporating household production generates different results to many policy questions, as mentioned above. Hence, it seems natural to use an integrated model to study the cost of inflation. We plan to pursue this in future work; for now, to maintain focus, we concentrate mainly on the effects of inflation on the observable variables mentioned above.

inflation on housing demand by evaluating how it affects after-tax mortgage payments or the user-cost of home capital, e.g., Kearn (1979) shows that inflation front loads real payments on a long-term fixed-rate mortgage, which affects the desired quantity of housing. Others, including Follain (1982) and Poterba (1991), argue that the tax-deductibility of nominal interest payments and thus the after-tax cost of mortgage finance increased the demand for housing as inflation increased in the 1970s. We think these are complementary ideas, but we want to focus on a different channel.

More recently, Brunnermeier and Juiliard (2008) demonstrate that money illusion, involving the confusion of nominal and real interest rates, can directly link inflation and the price of housing. While this may have a grain of truth, we prefer to have the agents in our model rational. More closely related to our paper is recent work by Piazzesi and Schneider (2010) that studies how households optimally adjust their portfolio shares of housing and financial wealth in response to inflation. Specifically, in their framework, households shift into housing in response to inflation because inflation acts as a tax on returns to financial assets but not housing. In a related but different vein, He et al. (2011) model housing as an asset that can bear a liquidity premium because it can be used to collateralize loans in models where credit markets are imperfect due to lack of commitment. These papers are related to our approach in the sense that they treat houses as assets. But we emphasize that to study monetary issues it is better – i.e., more enlightening and no more difficult – to model the role of money explicitly. Further, we take household production seriously. Again, a house is more than an asset, it is an input into activity that, combined with time and other inputs, generates output from which we derive direct utility, while other assets simply give off dividend or interest payments that augment budget equations.

Lest readers are misled at this point, we allow for frictions in goods markets that are common in the search literature, which is part of the reason why money is essential, but in our baseline model we abstract from frictions in the housing market. Household capital,

exactly like market capital in most of macroeconomics and growth theory, is bought and sold in frictionless competitive markets. This is despite the fact that we think search theory is natural for studying housing, and we find interesting the research that does use search theory for this purpose, including Wheaton (1990), Albrecht et al. (2007), Caplin and Leahy (2008), Coulson and Fisher (2009), Ngai and Tenreyro (2009), Novy-Marx (2009), Piazzesi and Schneider (2009), Smith (2009), Head and Lloyd-Ellis (2010), Head et al. (2010), and Burnside et al. (2011). While this is interesting, we prefer to focus on other aspects of housing, including the notion that it constitutes an input into the home production process; we leave to future work an attempt to incorporate realistic frictions in the buying and selling of houses, along with household production and the ingredients in modern monetary theory.

In our empirical section we show results for largest possible samples that include the 2000s. However, when we take the model to the data, we focus on the period prior to the 2000s. The model does almost as well when fit to the entire sample, but there is a good argument for stopping at 2000, after which several facts indicate there is something different going on. First, it is commonly heard that a house-price bubble began around 2000. It is clear from the data that there was a big runup in prices starting then, which ultimately collapsed. Second, there was a huge increase in home equity loans around the same time (home equity loans over GDP more than tripled). Third, there was an increase in construction, followed by a decrease as the bubble burst. Our model is not designed for generating bubbles, and we abstract from the idea that home equity can be used to collateralize loans.

He, Wright and Zhu (2011) present a model that is designed to capture these phenomena.<sup>3</sup>

In that model, house prices can display a variety of complicated dynamic paths, including

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<sup>3</sup>In that model, as in ours, agents participate in both centralized and decentralized markets, and in the latter neither barter nor unsecured credit are viable. In one version of the model, households use money borrowed from banks, as in Berentsen, Camera and Waller (2007), but cash loans must be secured by home equity. In another version, they use home equity to collateralize consumption loans directly, without using cash, as in Kiyotaki and Moore (1997,2005). The use of home equity to secure credit implies that equilibrium house prices can bear a liquidity premium: people are willing to pay more than the fundamental price, defined as the discounted marginal utility of living in the house, because home ownership provides security in case one needs a loan (intuitively, this is similar to fiat currency bearing a liquidity premium).

cyclic, chaotic and stochastic (sunspot) equilibria. Some of the equilibria resemble the data, post 2000, at least qualitatively, in the following sense. Imagine that innovations in financial markets cause an increase in the use of home equity loans. Although the model has a unique steady state, there is a dynamic indeterminacy. In some of the equilibria, after financial innovation, there is a transition path along which consumers use home equity to dramatically increase borrowing, where house prices first soar and then collapse, and where construction first increases then decreases as we approach the new steady state.<sup>4</sup>

Although we also have credit frictions, and we similarly model housing production, we do not attempt to incorporate financial innovation, abstract from home equity loans, and ignore bubbles. This is not a bad approach to the situation up to 2000, but makes our model less well suited for the period since, especially if one interprets it a transition between steady states. One can think of the analysis here as applying to “normal” times, when house prices are better understood as determined by fundamentals – preferences, technology and government policy – and not by bubbles or transitions after financial innovation. Having said that, an upside to the analysis here is that we take the quantitative work seriously, measuring how much we can explain in “normal” housing markets in terms of fundamentals, including monetary policy, instead of simply displaying paths that resemble the data in a qualitative sense. For our exercise, it is useful to start with observations that are relatively stationary. From the data this suggests dropping the post-2000 period, and the theoretical

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<sup>4</sup>This formalizes Reinhart and Rogoff’s (2009) claim that financial innovation allowed consumers “to turn their previously illiquid housing assets into ATM machines.” The financial development they have in mind is *securitization*. As Holmstrom and Triole (2011) put it, “Securitization, by making [previously] nontradable mortgages tradable, led to a dramatic growth in the US volume of mortgages, home equity loans, and mortgage-backed securities in 2000 to 2008, partly in response to increased global demand for savings instruments.” Ferguson (2008) also contends this “allowed borrowers to treat their homes as cash machines.” Further evidence comes from Mian and Sufi (2011), who estimate homeowners extracted 25 cents for every dollar increase in home equity, show these loans added \$1.25 trillion to household debt during 2002-2008, and emphasize the borrowed funds were used by households for consumption, rather than, e.g., paying off credit card debt or purchasing financial assets. Relatedly, Harding, Rosenthal and Sirmans (2007) argue that with a depreciation rate on houses around 2.5 percent and a discount rate around 3 percent, the house rent-price ratio should be 5.5. Campbell, Davis, Gallin and Martin (2009) find that from 1975 to 1995, the ratio is around 5, then declines to 3.7 in 2007. This is consistent with a theory where the increased use of home equity loans has allowed house prices to bear a liquidity premium in recent years.

analyses mentioned above say this might be a good idea in terms of theory.

The rest of the paper is organized as follows. Section 2 discusses the data and documents the facts described above. Section 3 presents the general theoretical framework, describing the roles of households, producers, retailers and government. Section 4 discusses equilibrium for the model. This general framework is somewhat intricate, since the issues at hand are complicated. Therefore, in Section 5, we present a stripped-down version in order to better develop economic intuition. In this simplified setting, with no investment, but still with housing and household production, we are able to prove several rather strong results. In particular, we show analytically that although the price of housing relative to a price index defined by retail market consumption may fall with inflation or nominal interest rates, the following four variables rise with inflation or nominal interest rates: (i) the price of housing relative to a wholesale price index; (ii) the price and value of the housing stock relative to retail spending; (iii) the price and value of the housing stock relative to wholesale spending; and (iv) the price and value of the housing stock relative to the money supply. These are theorems that hold under quite general and natural conditions. To see how big the effects might be, Section 6 presents the quantitative analysis, where we describe our functional forms, calibration method, and results. While there are many details to discuss, by way of preview, the theory seems to work quite well in terms of describing the data. We conclude in Section 7.



## 2 Data

The first order of business is to discuss the facts. In this section we build the case that inflation and the value of home capital, scaled by GDP and M1, are positively correlated. To this extent, we present a variety of evidence over time and across countries that, when considered at all once, makes a strong case.

### 2.1 United States

For the United States, we consider four estimates of the value of home capital. In each case, home capital is computed as the nominal stock of durable goods as computed by the BEA plus an estimate of the value of housing wealth. The four estimates represent four different approaches to measuring the value of housing wealth. Details on all our data sources are available in the appendix.

Our first estimate of the value of housing of housing wealth in the United States is from Davis and Heathcote (2007). Of all our measures of housing wealth, we believe the Davis and Heathcote (DH) measure is the most accurate, however the available sample is relatively short, starting in only 1975. Figure 1 shows the relationship of the DH-based estimate of Home Capital to inflation (top panel) and the 3-month T-Bill (bottom panel) over the 1975-2009 range. In this and in all subsequent figures, the left-hand graphs plot the raw time-series and the right-hand graphs are scatter diagrams, with observations from different decades separately marked. The scatter diagrams also report (a) semi-elasticities (“elas”), computed from a regression of the log of the ratio of home-capital to GDP against the inflation rate or the rate of the 3-month T-Bill, and (b) raw correlations of the two plotted variables (“corr”). The blue solid line in the scatter diagrams shows the predicted relationship for the plotted data in the 2000-2009 range and the black solid line shows the predicted relationship for all years up through 1999.

The shaded areas of the time-series plots in Figure 1 make obvious that the ratio of

home capital to GDP behaved unusually in the decade of the 2000s, at least relative to the previous 25 years of data. Unlike some other recent papers discussed in the Introduction, this paper does not have much to say about the recent housing boom and bust. For our baseline calibrations, we omit data from the 2000s, but we plot it here for completeness. Focusing on just the 1975-1999 period, we take away two results from Figure 1. First, home capital scaled by GDP is positively correlated with inflation and the 3-month T-Bill, with a correlation of about 62 percent. Second, the semi-elasticity of home capital with respect to the level of inflation is about 1.1 percent. We also note that, home capital scaled by GDP is positively correlated with inflation and the 3-month T-Bill in the decade of the 2000s – but, as the graphs indicate, this decade looks sufficiently different from the earlier period.<sup>5</sup>

In Figure 2, we plot the DH-based estimate of home capital scaled by sweep-adjusted M1 (M1S) as computed by Cynamon et al (2006).<sup>6</sup> The 2000-2009 period does not look particularly unusual relative to the 1975-1999 range in both the time-series and the scatter graphs. These graphs make evident that home capital scaled by M1 is correlated with inflation and the 3-month T-Bill, with an estimated semi-elasticity in the 1975-1999 period of somewhere between 2.6 and 3.7 percent, and a correlation of at least 0.56.

Figures 3 and 4 show the same relationships using data on housing wealth from the Flow of Funds Accounts of the United States (FFA). The FFA data have the advantage that they span a longer time period (1952-), however we believe the FFA accounts provide unreliable estimates of the change in housing value over the 1975-1990 period, a key period of our analysis because of the dramatic increase and decline in inflation in that period.<sup>7</sup> The top

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<sup>5</sup>In fact, if we compute the elasticity in the sample 1975-2009 it is essentially zero. But, as it is clear from the figure, this is not because there is no relationship but because the relationship changes.

<sup>6</sup>The M1S series adjusts traditional measures of the money supply, like M1, for the practice of commercial banks since the 1990s of moving customers' checkable deposits into overnight money market accounts (with, in many cases, no benefits to the customers). This practice distorts the end-of-day (end-of-month, etc.) checkable balances held at commercial banks, and creates a substantial divergence in the standard measure of M1.

<sup>7</sup>We believe the estimates of housing wealth are unreliable because the capital gains to housing that are implied by the FFA data in this period do not align with predicted estimates of capital gains we can compute using available house price indexes. For the 1975-1990 period, the FFA data are not constructed to match

panel of Figure 3 shows that there is about a zero correlation of the ratio of home capital to GDP to inflation. However, home capital scaled by M1 is positively correlated with inflation (semi-elasticity of 5.1 percent, Figure 4) and home capital scaled by both GDP and M1 are positively correlated with the 3-month T-Bill: the semi-elasticity of home capital to GDP is 1.3 percent and of home capital to M1 is 9.2 percent.

For our third estimate of the value of housing wealth, we use the replacement cost of the stock of housing structures, as estimated by the BEA. This is the measure of housing wealth that has previously been used by macroeconomists studying home production (McGrattan et al). The advantages to these data, besides their use by other macroeconomists, are that they are available over a long period of time and the methods the BEA use to compute the data are well documented. The disadvantage of course is that these data do not include the value of land. Land currently accounts for about one third of the value of housing in the aggregate, although prior to 1970 land's share of housing value is estimated to be between 10 and 20 percent (Davis and Heathcote 2007). Figure 5 shows this BEA-based estimate of home capital scaled by GDP and Figure 6 shows it scaled by M1 over the 1952-2009 period.<sup>8</sup> Again, Figures 5 and 6 show a positive relationship of home capital scaled by GDP and by M1 with respect to inflation and the 3-month T-Bill. Figure 5 reports a semi-elasticity of home capital scaled by GDP with respect to inflation and the 3-month T-Bill of about 1 percent. Figure 6 shows semi-elasticities of this measure of home capital scaled by M1 of about the same order of magnitude as when computed with the FFA data: the semi-elasticity with respect to inflation is 6.2 percent and 8.9 percent with respect to the 3-month T-Bill.

Figure 7 shows data for our final measure of home capital. Here, we use housing wealth

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predicted capital gains to house price indexes. Rather, they spline together estimates of the aggregate value of housing from the Annual Housing Survey and then the Americal Housing Survey. The process of splining these different data sources together has created an unusual sequence of implied capital gains. This is unlike the DH data, which is benchmarked to the 2000 Decennial Census of Housing, and where capital gains are taken directly from house price indexes by construction.

<sup>8</sup>We chose 1952 to be consistent with the starting date with the FFA data, and for other reasons familiar to macroeconomists: this excludes the Great Depression, World War II, and much of the Korean War.

computed directly from various Decennial Censuses of Housing (DCH), again computed by Davis and Heathcote (2007). The advantages to these data are that they provide an accurate reading of the aggregate value of housing and are available back to 1930. The disadvantage is that they are only available every 10 years. The top panel of Figure 7 shows home capital scaled by GDP as compared to inflation (left) and the AAA corporate bond rate (right).<sup>9</sup> To try to remove the influence of an odd reading of any one year's inflation rate, the inflation rate we use here is the 3-year moving average of inflation. The top panel shows the ratio of home capital to GDP is negatively correlated with inflation but is positively correlated with the AAA rate. This difference in the signs of these correlations is due to the divergent behavior of inflation as compared to the AAA rate in 1930 and 1940.<sup>10</sup> With the 1930 and 1940 data points removed, the semi-elasticity of the ratio of home capital to GDP to inflation is about 1 percent. The bottom panel shows the same data, but for home capital scaled by M1. The bottom panel shows the ratio of home capital to M1 is positively correlated with respect to both inflation and the AAA rate.

In summary, we believe the compendium of evidence we have provided across a variety of sources documents that the value of home capital in the United States as scaled by GDP and again by M1 is positively correlated with inflation and with interest rates.

We note here that we know of one data source for housing that does not show a similar (positive) historical relationship with inflation and interest rates: The house price index that was constructed by Robert Shiller for his book *Irrational Exuberance*, Shiller (2005). In Figure 8, we show the Shiller House Price Index (HPI) divided by GDP (top panel) and M1 (bottom panel) are compared to inflation over the 1952-2009 period. Broadly speaking, the left panel shows that over the 1952-2009 period, the Shiller HPI declined relative to GDP and to M1. Given these long-term trends, it's hard to know what to make of the correlations

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<sup>9</sup>Data for the 3-month T-Bill are only available starting in 1934. The AAA rate data are available starting in 1919.

<sup>10</sup>In 1930 the 3-year moving average of inflation was -8.7 percent and the AAA rate was 4.5 percent. By 1940 the 3-year moving average of inflation had increased to 5.5 percent and the AAA rate fell to 2.8 percent.

shown in the scatter diagrams in the right panels.

In Table 1, we document exactly why the Shiller data are so different from data we report in Figures 1-7. For each decade, column 1 of this table reports the growth of the Shiller HPI; column 2 reports growth in the average price of housing units (as computed from the various Decennial Censuses by Davis and Heathcote, 2007); column 3 reports growth in the total number of housing units; and column 4 reports growth in nominal GDP. Summarizing, the Shiller HPI declines relative to GDP (whereas housing wealth relative to GDP has not) for two reasons. First, in every decade up through 1990, the Shiller HPI understates growth in the average price of housing units.<sup>11</sup> The Shiller HPI most understates growth during the period of highest inflation, 1970-1980. Second, the Shiller HPI is a price index, so by construction it does not account for any change in quantity. Table 1 shows that in every decade the number of housing units has been increasing. In fact, the number of housing units increased by about 30 percent per decade from 1950-1980, accounting for a sizeable portion of the increase in housing wealth. To sum up, we are comfortable using housing wealth scaled by GDP for our analysis because these two series have increased at roughly the same rate over the entire 1950-2000 period. Columns 2 and 3 of Table 1 show that the sum of percent price changes and of percent quantity changes from 1950-2000 is 528 percent and column 4 shows the sum of nominal GDP percent changes is 517 percent. In comparison, column 1 shows that the sum of price changes from the Shiller HPI over the same period is only 284 percent.

## 2.2 Other Countries

To establish the robustness of the positive relationship between housing wealth and inflation it is also instructive whether the data for other countries show similar relationships. Unfortunately, data on housing wealth prior to about 1990 and certainly prior to 1980 are

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<sup>11</sup>This could reflect a bias in the Shiller HPI or could reflect growth in the average quality of housing units.

virtually nonexistent in almost every country outside of the United States. However, various estimates of house prices – either the average price of a housing unit, or a price index for houses – have been constructed for a relatively long time series across a number of countries. Obviously, and for reasons we discussed earlier, the use of house prices is not ideal in our application – in areas where housing is elastically supplied, quantities can change rather than prices. But house prices are all we have, and therefore we report them.

In figures 9 through 14, we graph the ratio of house prices to GDP against inflation for 16 advanced economies. The left panel of each graph plots the raw time series and the right panel plots scatter diagrams, with different markings for different decades – the same as in the other figures. In these graphs, we do not distinguish 2000-2009 from other decades, as the housing boom and bust so prevalent in the U.S. data is not as readily apparent in many of the countries we study.

Figures 9 and 10 show data for the countries for which we could directly track down source data on house prices: Belgium (1961-2009), France (1953-2009), Ireland (1971-2009), Switzerland (1970-2009), and the United Kingdom (1953-2009).<sup>12</sup> The panels of Figures 9 and 10 show that in all countries except Belgium, house prices and inflation are positively correlated, although sometimes this correlation is quite noisy.

Figures 11 through 14 show the eleven countries for which we have house price data that are from the Bank for International Settlements (BIS).<sup>13</sup> The data for each of these countries spans the 1971-2009 period. We group these countries separately from the countries shown in figures 9 and 10 because we are unsure of exactly where these data come from. For example, to the best of our knowledge the data on house prices in Australia are first available starting in 1986, however in our data set they begin in 1971. That said, we checked the annual growth

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<sup>12</sup>Data are available for France prior to 1953. We start in 1953 so our results are not unduly influenced by the WWII or its aftermath.

<sup>13</sup>These data were generously provided to us by Chrisophe Andre at the OECD. See Andre, C. (2010), “A Bird’s Eye View of OECD Housing Markets,” OECD Economics Department Working Papers, No. 746, OECD Publishing, for more of a discussion on these data.

rates of house prices from the BIS data against the growth rates of house prices from the source data for the five countries in Figures 9 and 10. The growth rates closely align, giving us at least some measure of confidence in the other BIS data. All caveats aside, the data in Figures 11 through 14 speak strongly: In nine of eleven advanced economies, the exceptions being New Zealand and Spain, the ratio of house prices to GDP and inflation are positively correlated.

### 3 The Model

Time is discrete and continues forever. Each period is divided into two subperiods: the first subperiod is for production, and looks somewhat (but not exactly) like the centralized market in Lagos and Wright (2005); the second subperiod is for consumption, and looks somewhat like the decentralized market in that framework. There are four types of agents in the economy:  $[0, 1]$  continuum of homogeneous households; a set of production firms, the cardinality of which does not matter; a  $[0, n]$  continuum of retail firms, where  $n$  does matter; and government. Households, who work in the first subperiod and consume in the second, discount at  $\beta = 1/(1 + \rho)$ , with  $\rho > 0$ , across periods (but not across subperiods, without loss of generality). Production firms operate in the first subperiod to produce an intermediate good  $x$  that is purchased wholesale by retailers, to be sold as final consumption goods to households in the second subperiod. Some intermediate goods are also purchased by households, for investment, as home and market capital. The only role of government is to adjust the money supply and levy a lump sum tax  $T$ .<sup>14</sup>

To go into more detail, in the first subperiod households supply labor at nominal wage  $w$ , rent market capital to production firms at nominal rate  $r$ , and adjust their portfolios; they do not consume until the second subperiod. We use a quasi-linear within-period utility function,  $U(c_m, c_n) - A_m \ell_m - A_n \ell_n$ , where  $c_m$  and  $c_n$  denote market and nonmarket (home) consumption, while  $\ell_m$  and  $\ell_n$  denote market and nonmarket (home) labor,  $U(\cdot)$  is strictly increasing and concave and  $A_m$  and  $A_n$  are positive constants denoting the utility cost of one unit of market and nonmarket labor, respectively. There are two nominal assets, money  $m$  and a risk-free bond  $b$ ; the former is used as a medium of exchange, while the main role of the latter is merely to compute a nominal interest rate. There are three real assets, or types of capital: market capital  $k_m$ , residential structures  $k_s$ , and land  $k_l$ . As is standard,

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<sup>14</sup>In future work we will also include proportional taxes, since this is useful in quantifying the model, and allows one to study fiscal in addition to monetary policy.



$k_m$  is an input to the market production function  $f(\ell_m, k_m)$ . There is also a nonmarket production function  $g(\ell_n, k_n)$ , where  $k_n$  is nonmarket capital, or housing, which combines residential structures and land according to  $k_n = h(k_s, k_l)$ ; one could alternatively simply say that home production has three inputs, labor, structures and land, but for the purposes at hand, we prefer to have a measure of housing capital as an explicit function of structures and land. In any case, the supply of land is fixed and normalized to 1. The technologies  $f(\cdot)$ ,  $g(\cdot)$  and  $h(\cdot)$  are strictly increasing and concave. We also usually assume they are homogeneous of degree 1.

In the second subperiod retail markets convene, where we adopt the following specification. A measure  $\sigma_2$  of retailers and households meet in one location where credit is available, a measure  $\sigma_1$  meet in a different location where it is not, and a measure  $\sigma_0 = 1 - \sigma_1 - \sigma_2$  simply do not get to trade that period.<sup>15</sup> Since Kocherlakota (1998), it has been understood that a lack of perfect record keeping is the key ingredient for generating an essential role for money, so the difference between these locations can be interpreted in terms of the information technology.<sup>16</sup> In the location/market where record keeping is available, and hence credit is feasible, retailers accept promises of payments in the following period. In the location/market where record keeping is not available, trade requires quid pro quo, and we assume that fiat currency is the only object that can serve in this capacity. This is not the place to go into a lot of detail as to why, say, bonds, or claims to capital, cannot be used as a medium of exchange; although this is a very important (and not totally resolved) issue, all we can do here is refer readers to papers where it is addressed using information theory, e.g., Lester et al. (*in press*) and references contained therein.

In each retail market, all agents are assumed to be Walrasian price takers. The inter-

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<sup>15</sup>To remember the notation, the  $j$  in  $\sigma_j$  refers to the number of payment instruments available in a particular market: with probability  $\sigma_1$  there is only one, money; with probability  $\sigma_2$  there two, money and credit; and probability  $\sigma_0$  there are none.

<sup>16</sup>In addition to Kocherlakota (1998), see Wallace (2001, 2010) and the surveys mentioned in fn. 1 for explicit details.

pretation is that there are large numbers – measures  $\sigma_1$  and  $\sigma_2$  – of traders in the money and credit markets, so they take prices as given, as in the search-based labor-market model in Lucas and Prescott (1974) or Alvarez and Veracierto (2000). By contrast, many models in monetary theory assume agents meet bilaterally and bargain over the terms of trade, more along the lines of the labor-market model in Mortensen and Pissarides (1994). Despite the fact that our retail markets are Walrasian, there are search frictions in the sense that households and retailers randomly find themselves in a market where credit can be used, where only money be used, or neither, with probabilities  $\sigma_2$ ,  $\sigma_1$ , or  $\sigma_0$ . Also, although this does not matter much, to allow for bilateral trade in future applications we assume the same number of retailers as households in each market. Hence, since the ratio of the total measure of retailers to households is  $n$ , for retailers the probability of being in a market where credit is available is  $\sigma_2/n$  and the probability of being in a market only money can be used is  $\sigma_1/n$ . We can of course assume that households (and/or retailers) have trading opportunities with probability 1, but we allow search frictions because they are interesting and because they are potentially relevant for quantitative work.<sup>17</sup>

### 3.1 Households

Households' state vector in the first subperiod contains their portfolio of money, bonds, market capital, structures and land,  $z = (m, b, k_m, k_s, k_l)$ , plus outstanding nominal debt owed (to retailers) from the previous period,  $d$ . We assume all debt is paid off in the first subperiod, without loss of generality, given quasi-linear utility. Households' state vector in the second subperiod contains their portfolio brought out of the first subperiod,  $\hat{z}$ , plus their housing capital  $k_n$  which depends on structures and land at the start of the first subperiod. Letting  $W(z, d)$  and  $V(\hat{z}, k_n)$  be the value functions in the first and second subperiod, we

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<sup>17</sup>Although we concentrate on price-taking behavior, for now, the plan is to return to bargaining in future work. See Rocheteau and Wright (2005, 2009) for comparisons between different pricing mechanisms, including bargaining, price taking and price posting, in monetary theory and quantitative work.

have

$$W(z, d) = \max_{\ell_m, \hat{z}, k_n} \{-A_m \ell_m + V(\hat{z}, k_n)\}, \quad (1)$$

where the maximization is subject to  $k_n = h(k_s, k_l)$  plus the budget constraint

$$\hat{m} + p_b \hat{b} + p_x \hat{k}_m + p_x \hat{k}_s + p_l \hat{k}_l + d + T = w \ell_m + r k_m + m + b + p_x (1 - \delta_m) k_m + p_x (1 - \delta_s) k_s + p_l k_l$$

where  $p_b$ ,  $p_l$  and  $p_x$  are the prices of bonds, land and intermediate output, respectively.<sup>18</sup>

Notice that the way we specified this problem makes it look like households build their own houses, by buying land as well as intermediate goods to augment structures. It is easy to show, however, that this setup is equivalent to one in which households buy and sell houses directly in a competitive market, where they are produced by builders using the same technology  $k_n = h(k_s, k_l)$  (we give more details on this at the end of Section 4). The market value of a house equals the cost of building it – i.e., the cost of the land and the structure purchased at competitive prices  $p_l$  and  $p_x$ . In the spirit of the usual presentation of standard growth theory, where households own market capital and rent it to firms, we adopt a specification where they also own land and structures that are combined into housing, but little of substance hinges on this. Also notice that the allocation of time to home production  $\ell_n$  is decided in the second subperiod, after events in the retail market have been realized. We also solved a version where  $\ell_n$  along with  $\ell_m$  were decided in the first subperiod, and the results were similar; of course, if there is no uncertainty in the retail market these are equivalent.

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<sup>18</sup>We make a few comments about this problem. First, the output of production firms is an intermediate good  $x$  that can be purchased by retailers (see below) or by households and used as either market or residential capital. As in standard growth theory, output and capital are the same physical objects and hence have the same price  $p_x$ . Also as in standard growth theory, investment in new capital only becomes productive next period, which is why  $k_n = h(k_s, k_l)$  enters  $V(\cdot)$  as a state variable, where  $k_n$  depends on  $k_s$  and  $k_l$ , not  $\hat{k}_s$  and  $\hat{k}_l$ . Also, structures and market capital depreciate at potentially different rates  $\delta_m$  and  $\delta_s$  while land does not depreciate at all. Finally, note that in principle households also get a dividend from the ownership of firms, but we ignore this in the budget equation because in equilibrium it is 0.

Eliminating  $\ell_m$  and  $k_n$  using the constraints, we reduce (1) to

$$W(z, d) = \frac{A_m}{w} [rk_m + m + b + p_x(1 - \delta_m)k_m + p_x(1 - \delta_s)k_s + p_l k_l - T - d] \\ + \max_{\hat{z}} \left\{ -\frac{A_m}{w} (\hat{m} + p_b \hat{b} + p_x \hat{k}_m + p_x \hat{k}_s + p_l \hat{k}_l) + V[\hat{z}, h(k_s, k_l)] \right\}. \quad (2)$$

This standard maximization problem has first-order conditions

$$\begin{aligned} \hat{m} &: \frac{A_m}{w} = \frac{\partial V}{\partial \hat{m}} \\ \hat{b} &: p_b \frac{A_m}{w} = \frac{\partial V}{\partial \hat{b}} \\ \hat{k}_m &: p_x \frac{A_m}{w} = \frac{\partial V}{\partial \hat{k}_m} \\ \hat{k}_s &: p_x \frac{A_m}{w} = \frac{\partial V}{\partial \hat{k}_s} \\ \hat{k}_l &: p_l \frac{A_m}{w} = \frac{\partial V}{\partial \hat{k}_l}. \end{aligned}$$

These imply that the choice of  $(\hat{m}, \hat{b}, \hat{k}_m)$  is independent of  $(z, d)$ , as is standard in models with quasi-linear utility functions (Lagos and Wright 2005; Aruoba et al. 2011). The envelope conditions are

$$\begin{aligned} \frac{\partial W}{\partial m} &= \frac{A_m}{w} \\ \frac{\partial W}{\partial b} &= \frac{A_m}{w} \\ \frac{\partial W}{\partial k_m} &= [r + (1 - \delta_k) p_x] \frac{A_m}{w} \\ \frac{\partial W}{\partial k_s} &= (1 - \delta_s) p_x \frac{A_m}{w} + h_1(k_s, k_l) \frac{\partial V}{\partial k_n} \\ \frac{\partial W}{\partial k_l} &= p_l \frac{A_m}{w} + h_2(k_s, k_l) \frac{\partial V}{\partial k_l} \\ \frac{\partial W}{\partial d} &= -\frac{A_m}{w}, \end{aligned}$$

These imply that  $W(\cdot)$  is linear in non-housing wealth, as is also standard in these models.

In the second subperiod, in the retail market, three events may occur for households: with probability  $\sigma_2$  they have an opportunity to trade using credit or money; with probability  $\sigma_1$

they have an opportunity to trade but only using money; or with probability  $\sigma_0$  they have no opportunity to trade. Conditional on these events the value function is denoted  $V^2(\cdot)$ ,  $V^1(\cdot)$  or  $V^0(\cdot)$ , and unconditionally we have

$$V(\hat{z}, k_n) = \sigma_2 V^2(\hat{z}, k_n) + \sigma_1 V^1(\hat{z}, k_n) + \sigma_0 V^0(\hat{z}, k_n). \quad (3)$$

In what follows we use two standard results: First, in the market where money must be used, households spend all their money (intuitively, they would never need to bring more than they actually use). Second, and in the market where credit can also be used, all agents are indifferent about using either credit or money, so without loss of generality we assume they use credit only.

Let  $p_1$  and  $p_2$  be the retail prices of consumption in the markets where money and credit are used, respectively. Now, using the home production constraint  $c_m = g(\ell_n, k_n)$ , we have the three conditional second-subperiod problems for a household:<sup>19</sup>

$$\begin{aligned} V^1(\hat{z}, k_n) &= \max_{c_m, \ell_n} \left\{ u[c_m, g(\ell_n, k_n)] - A_n \ell_n + \beta W(0, \hat{b}, \hat{k}_m, \hat{k}_s, \hat{k}_l, 0) \right\} \text{ st } p_1 c_m = \hat{m} \\ V^2(\hat{z}, k_n) &= \max_{c_m, \ell_n} \left\{ u[c_m, g(\ell_n, k_n)] - A_n \ell_n + \beta W(\hat{m}, \hat{b}, \hat{k}_m, \hat{k}_s, \hat{k}_l, d) \right\} \text{ st } p_2 c_m = d \\ V^0(\hat{z}, k_n) &= \max_{c_m, \ell_n} \left\{ u[c_m, g(\ell_n, k_n)] - A_n \ell_n + \beta W(\hat{m}, \hat{b}, \hat{k}_m, \hat{k}_s, \hat{k}_l, 0) \right\} \text{ st } c_m = 0. \end{aligned}$$

Denote the solutions to these three problems by  $(c_m^j, c_n^j, \ell_n^j)$  for  $j = 1, 2, 0$ . These satisfy the following conditions: in each case we have the home production constraint  $c_n^j = g(\ell_n^j, k_n)$ ; when  $j = 1$ ,  $c_m^j$  and  $\ell_n^j$ , satisfy  $c_m^1 = \hat{m}/p_1$  and  $u_2(c_m^1, c_n^1) g_1(\ell_n^1, k_n) = A$ ; when  $j = 2$ , they satisfy  $u_1(c_m^2, c_n^2) = p_2 \beta A_m / w'$  and  $u_2(c_m^2, c_n^2) g_1(\ell_n^2, k_n) = A_n$ ; and when  $j = 0$  they satisfy  $c_m^0 = 0$  and  $u_2(0, c_n^0) g_1(\ell_n^0, k_n) = A_n$ . As can be seen from these conditions, the choice of market and home consumption  $(c_m^j, c_n^j, \ell_n^j)$  depend on market prices, and also on home capital  $k_n$ , since this determines the mapping from home work  $\ell_n^j$  and home consumption  $c_n^j$ , naturally.

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<sup>19</sup>At the risk of appearing overly pedantic by writing the third problem in terms of choosing  $c_m$  subject to  $c_m = 0$ , we find it convenient to have similar expressions for all three problems.

Combining what we now know, we can express (3) as

$$V(\hat{z}, k_n) = \sigma_1 \left[ u(c_m^1, c_n^1) - A_n \ell_n^m - \beta \hat{m} \frac{A_m}{w'} \right] + \sigma_2 \left[ u(c_m^2, c_n^2) - A_n \ell_n^2 - \beta p_2 c_m^2 \frac{A_n}{w'} \right] + \sigma_0 \left[ u(0, c_n^0) - A_n \ell_n^0 \right] + \beta W(\hat{z}, 0), \quad (4)$$

where  $w'$  denotes the wage next period (and similarly for other variables). Two useful conditions from (4) are

$$\begin{aligned} \frac{\partial V}{\partial \hat{m}} &= \frac{\sigma_1 u_1(c_m^1, c_n^1)}{p_1} + (1 - \sigma_1) \beta \frac{A_m}{w'} \\ \frac{\partial V}{\partial \hat{k}_n} &= \mathbb{E}(u_2 g_2), \end{aligned}$$

where we define the expected marginal utility of housing, which arises from its use in home production, as

$$\mathbb{E}(u_2 g_2) = \sigma_1 u_2(c_m^1, c_n^1) g_2(\ell_n^1, k_n) + \sigma_2 u_2(c_m^2, c_n^2) g_2(\ell_n^2, k_n) + \sigma_0 u_2(0, c_n^0) g_2(\ell_n^0, k_n). \quad (5)$$

Combining the above results, we can now simplify the first-order conditions to

$$\frac{A_m}{w} = \frac{\sigma_1 u_1(c_m^1, c_n^1)}{p_1} + (1 - \sigma_1) \beta \frac{A_m}{w'} \quad (6)$$

$$\frac{A_m}{w} p_b = \beta \frac{A_m}{w'} \quad (7)$$

$$\frac{A_m}{w} p_x = \beta \frac{A_m}{w'} [r' + (1 - \delta_m) p'_x] \quad (8)$$

$$\frac{A_m}{w} p_x = \beta \frac{A_m}{w'} (1 - \delta_s) p'_x + \beta h_1(\hat{k}_s, \hat{k}_l) \mathbb{E}(u_2 g_2) \quad (9)$$

$$\frac{A_m}{w} p_l = \beta \frac{A_m}{w'} p'_l + \beta h_2(\hat{k}_s, \hat{k}_l) \mathbb{E}(u_2 g_2). \quad (10)$$

Given the state  $(z, d)$ , the solution to the household problem is characterized by: a new portfolio  $\hat{z} = (\hat{m}, \hat{b}, \hat{k}_m, \hat{k}_s, \hat{k}_l)$  satisfying (6)-(10); market work  $\ell_m$  as given by the budget equation; housing as defined by  $k_n = h(k_s, k_l)$ ; and second subperiod choices  $(c_m^j, c_n^j, \ell_n^j)$  described above. In particular, (7) implies

$$p_b = \beta \frac{w}{w'} = \frac{1}{(1 + \rho)(1 + \pi)}, \quad (11)$$

where  $\rho$  is the rate of time preference and  $\pi$  the inflation rate,  $1 + \pi = w'/w$ . Clearly, in this economy the real interest rate must be  $\rho$ , and if we define the nominal rate  $i$  using the Fisher Equation  $1 + i = (1 + \rho)(1 + \pi)$ , immediately (11) implies  $p_b = 1/(1 + i)$ . Households are happy to hold any  $b$  as long as this condition holds.

### 3.2 Production Firms

Producers are completely standard: a representative firm maximizes profit, and pays dividends to households, by hiring labor and capital, and selling output of the intermediate good  $X = f(L, K)$  at price  $p_x$ , all in the first subperiod:

$$\Pi^P = \max_{L, K} \{p_x f(L, K) - wL - rK\}. \quad (12)$$

As usual, the solution is characterized by  $w = p_x f_1(L, K)$  and  $r = p_x f_2(L, K)$ . Assuming that  $f(\cdot)$  is homogeneous of degree 1 implies  $\Pi^P = 0$ .

### 3.3 Retail Firms

Retailers purchase inventories of the intermediate good  $x$  in the first subperiod, and have an opportunity to trade for credit or for money in the second subperiod with probability  $\sigma_1/n$  and  $\sigma_2/n$ , respectively. They have a technology to convert  $x$  into  $c_m$ , and in general to potentially convert unsold consumption goods back to intermediate goods for the next period. There are several ways to handle the details, depending on the application at hand (see Choi and Wright 2011 for more details); we simply assume retailers can convert  $x$  one-for-one into  $c_m$ , and any unsold inventory left over when the retail market closes fully depreciate. Thus, retail profit is

$$\Pi^R = \max_x \left\{ -p_x x + \frac{\sigma_1}{n} p_b p_1 x + \frac{\sigma_2}{n} p_b p_2 x \right\}. \quad (13)$$

The first term in (13) is the cost of acquiring inventories; the second is expected revenue from cash sales, discounted by  $p_b = 1/(1 + i)$ , since this revenue is only available to be paid

out as dividends in the next period; and the final term is expected revenue from credit sales, also discounted. This uses the obvious result that retailers always sell everything they can, since unsold inventories fully depreciate. The first-order condition is

$$p_x = \frac{\sigma_1}{n} p_b p_1 + \frac{\sigma_2}{n} p_b p_2. \quad (14)$$

Given the linearity of their technology, as is standard, retailers are happy with any  $x$  as long as (14) holds, and in equilibrium  $\Pi^R = 0$ . They can finance purchases of  $x$  in the first subperiod by borrowing from households, who are happy to lend (i.e., to set  $b > 0$ ) as long as  $p_b = 1/(1+i)$ .

### 3.4 Government

The government controls the supply of money, which grows at constant rate  $\mu$ . It implements this using the lump sum tax  $T = M - M'$ , where  $M$  is the aggregate money supply and  $M' = (1 + \mu)M$  is the supply next period. We assume for simplicity that the government does no spending, but with quasi-linear utility, this is basically without loss of generality: if they were to spend new money instead of giving it away, for a given growth rate  $\mu$ , they would have to increase the tax (reduce the transfer), which would affect market labor supply  $\ell_m$  by no other households choices. This is significant to the extent that some people do not like models where government gives money away (at least, they do not find this realistic); in this framework, the results are basically unchanged when governments spend money (which is quite realistic) instead of giving it away. Also, we focus mainly on stationary outcomes, or steady states, where all real variables are constant and hence the inflation rate is  $\pi = \mu$ , a version of the Quantity Equation. Together with the Fisher Equation  $1+i = (1+\rho)(1+\pi)$ , this means that it is equivalent in this economy to target as a policy instrument either money growth  $\mu$ , inflation  $\pi$ , or the nominal rate  $i$ .



## 4 Equilibrium

As we said, we focus on steady states, where  $\pi = \mu$ . We now present the logic of equilibrium. First, we describe relative prices as a function of the allocation – i.e., quantities. Given this, we can eliminate prices and present the equilibrium conditions in terms of just quantities. An equilibrium allocation solves these conditions, and if one wants equilibrium prices, one can go back to the first part of the description to get them.

To begin, given an allocation, the producer problem determines relative factor prices  $w = p_x f_1(L, k_m)$  and  $r = p_x f_1(L, k_m)$ , where  $L$  is hours of market work averaged across households.<sup>20</sup> Then, from the households' first-subperiod problem, (7) and (10) determine

$$p_b = \frac{1}{1+i} \quad (15)$$

$$p_l = \frac{p_x f_1(L, k_m) h_2(k_s, 1) \mathbb{E}(u_2 g_2)}{A_m \rho}, \quad (16)$$

while the second-subperiod optimization conditions for  $c_m^1$  and  $c_m^2$ , the identity  $p'_x = (1 + \mu) p_x$  and market clearing  $\hat{m} = (1 + \mu) M$ , determine

$$p_1 = \frac{(1 + \mu) M}{x} \quad (17)$$

$$p_2 = \frac{(1 + \mu) p_x f_1(L, k_m) u_1(c_m^2, c_n^2)}{\beta A_m}. \quad (18)$$

Combining these with (14) from the retailers' problem and using the Fisher equation, we get the absolute price level

$$p_x = \frac{\sigma_1 \beta}{n - \sigma_2 f_1(L, k_m) u_1(c_m^2, c_n^2) / A_m} \frac{M}{x} \quad (19)$$

Holding quantities fixed, the absolute price level  $p_x$  is proportional to  $M$  – another version of the Quantity Equation – so that if we double  $M$  we can double all nominal prices and

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<sup>20</sup>As is standard, in this kind of model, households with different money or debt carried over from trading in the second subperiod of the previous period choose different  $\ell_m$  in the first subperiod of the current period. It is easy to derive individual labor supply from the budget equation, but, for our purposes, it suffices to consider only the aggregate  $L$ .

no real variables changes. From this, we have all relative prices, given the allocation, and in particular, we write

$$\frac{p_1}{p_x} = P(L, x, k_m, k_s, \ell_n^j). \quad (20)$$

Of course, prices depend on the entire allocation, generally, but since in equilibrium  $k_l = 1$ ,  $k_n = h(k_s, 1)$ ,  $c_m^1 = c_m^2 = x$  and  $c_n^j = g(\ell_n^j, k_n)$ , in (20) we can express the relative price as a function of only  $(L, x, k_m, k_s, \ell_n^j)$ . We now describe the allocation taking prices as given.

Taking first-subperiod quantities and prices as given, second-subperiod quantities  $(c_m^j, c_n^j, \ell_n^j)$ , for  $j = 0, 1, 2$ , are determined by

$$\begin{aligned} c_m^1 &= \frac{\hat{m}}{p_1} \\ A_n &= u_2(c_m^1, c_n^1) g_1(\ell_n^1, k_n) \\ u_1(c_m^2, c_n^2) &= \beta \frac{A_m}{w'} p_2 \\ A_n &= u_2(c_m^2, c_n^2) g_1(\ell_n^2, k_n) \\ c_m^0 &= 0 \\ A_n &= u_2(0, c_n^0) g_1(\ell_n^0, k_n), \end{aligned}$$

plus the home production constraint  $c_n^j = g(\ell_n^j, k_n)$ . And given second-subperiod quantities, first-subperiod quantities are summarized by  $(L, x, k_m, k_s)$ , since we know  $k_l = 1$  and  $k_n = h(k_s, 1)$ . Now  $(k_m, k_s)$  satisfy (8) and (9) from the households' problem, which in steady state can be reduced to

$$\begin{aligned} \rho + \delta_m &= f_2(L, k_m) \\ \rho + \delta_s &= \frac{f_1(L, k_m) h_1(k_s, 1) \mathbb{E}(u_2 g_2)}{A_m}. \end{aligned}$$

Since (7) and (10) merely determine  $p_b$  and  $p_l$ , the final condition from the households'

problem is (6), which reduces to

$$A_m (\sigma_1 + i) = f_1 (L, k_m) \sigma_1 u_1 (x, c_n^1) \frac{p_x}{p_1} (1 + i). \quad (21)$$

Finally, we have the feasibility condition (which as is standard can be derived by combining all agents' budget equations)  $f (L, k_m) = nx + \delta_k k_m + \delta_s k_s$ .<sup>21</sup>

This is a complete description of steady state. A more parsimonious definition can be given, as follows: Using (20), a steady state allocation is summarized by first-subperiod employment, output, market capital and residential structures, plus second-subperiod home production,  $(L, x, k_m, k_s, \ell_n^j, c_n^j)$ , solving

$$f (L, k_m) = nx + \delta_k k_m + \delta_s k_s \quad (22)$$

$$A_m (\sigma_1 + i) P (L, x, k_m, k_s, \ell_n^j) = (1 + i) f_1 (L, k_m) \sigma_1 u_1 (x, c_n^1) \quad (23)$$

$$\rho + \delta_m = f_2 (L, k_m) \quad (24)$$

$$\rho + \delta_s = f_1 (L, k_m) h_1 (k_s, 1) \mathbb{E} (u_2 g_2) / A_m \quad (25)$$

$$A_n = u_2 (x, c_n^1) g_1 [\ell_n^1, h (k_s, 1)] \quad (26)$$

$$A_n = u_2 (x, c_n^2) g_1 [\ell_n^2, h (k_s, 1)] \quad (27)$$

$$A_n = u_2 (0, c_n^0) g_1 [\ell_n^0, h (k_s, 1)] \quad (28)$$

$$c_n^1 = g [\ell_n^1, h (k_s, 1)] \quad (29)$$

$$c_n^2 = g [\ell_n^2, h (k_s, 1)] \quad (30)$$

$$c_n^0 = g [\ell_n^0, h (k_s, 1)]. \quad (31)$$

Heuristically, starting at the bottom, one can say that (26)-(31) give home work and home consumption for agents participating in the market where money is used, for agents participating in the market where credit is used, and for agents not participating in any market;

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<sup>21</sup>This condition can be obtained by combining the budget constraints of all households, who will differ according to their money holdings and debt, with the budget constraint of the government, and imposing equilibrium.

(24)-(25) give the stocks of market and residential capital as a generalization of the steady state condition in standard growth theory; and (22)-(23) give employment and output.

Given quantities satisfying the above definition, we solve for many other variables – e.g., prices are given by (15)-(19). Among other interesting variables, e.g., we can easily determine the average price in the retail market for consumption goods,

$$p_c = \frac{\sigma_1 p_1 + \sigma_2 p_2}{\sigma_1 + \sigma_2}. \quad (32)$$

This combined with (14) yields the gross retail markup,

$$\frac{p_c}{p_x} = \frac{n(1+i)}{\sigma_1 + \sigma_2}. \quad (33)$$

Nominal GDP, following the expenditure approach, is  $p_c(\sigma_1 + \sigma_2)x + p_x(\delta_m k_m + \delta_s k_s)$ , so since  $p_x$  is our price index real GDP is

$$y = \frac{p_c}{p_x}(\sigma_1 + \sigma_2)x + (\delta_m k_m + \delta_s k_s).$$

Alternatively following the production approach we get

$$y = f(L_m, k_m) \quad (34)$$

The difference between the two is given by interest payments by the retail firms. In our quantitative work below we use the latter definition but explore the consequences of using the former.

Velocity is  $v = p_x y / M'$ , using the (end-of-period or post-transfer) money supply, and since the representative household who trades in the market where money is used spends all his money,  $p_1 x = M'$ , we have

$$v = \frac{p_x y}{p_1 x}. \quad (35)$$

A standard measure of (end-of-period) money demand is  $M' / p_x y = 1/v$ , which can be interpreted as real balances scaled by real output, and is thought to be negatively related to  $i$

(see, e.g., Lucas 2000). Another notion of money demand is simply real balances  $M/p_x$ , which may be thought to be negatively related to  $i$  and positively related to  $y$ , but perhaps not linearly. Finally, and most interestingly, for this study, we can price housing as follows. As we said earlier, it is a straightforward reinterpretation of the model to introduce competitive builders, with profit

$$\Pi^B = p_n h(k_s, k_l) - p_x k_s - p_l k_l.$$

Maximization implies  $p_n h_1(k_s, k_l) = p_x$  and  $p_n h_2(k_s, k_l) = p_l$ , similar to the conditions from production firms, obviously. Using the homogeneity of degree 1 of the housing technology  $h(\cdot)$ , we have

$$p_n k_n = p_n [k_s h_1(k_s, k_l) + k_l h_2(k_s, k_l)] = p_x k_s + p_l, \quad (36)$$

after inserting the equilibrium conditions  $k_l = 1$ ,  $p_n h_1 = p_x$  and  $p_n h_2 = p_l$ . This is the value of the equilibrium housing stock. The price  $p_n$  is simply this value divided by the quantity  $k_n = h(k_s, 1)$ .

## 5 A Simplified Model

The general framework presented above is complicated, because we are interested in some complicated issues. To better develop some economic intuition, in this section, we eliminate investment decisions by fixing the stocks of market capital and residential structures at  $\bar{K}_m$  and  $\bar{K}_s$  and setting  $\delta_m = \delta_s = 0$ , just like we fix land at  $K_l = \bar{K}_l$  and set  $\delta_l = 0$  in the baseline model. Then the aggregate supply of housing in this economy is fixed at  $\bar{K}_n = h(\bar{K}_s, \bar{K}_l)$ . We also reduce household production to its barest bones, by assuming individuals derive utility directly from housing  $k_n = h(k_s, k_l)$ . Also, rather than trading  $k_s$  and  $k_l$ , individuals now trade  $k_n$  directly at price  $p_n$ , and trade  $k_m$  at price  $p_m$ . We also ignore bonds, and set  $\sigma_2 = 0$  and  $\sigma_1 = \sigma \in (0, 1)$ , so that if one trades at all in the second subperiod,  $c_m = \hat{m}/p_c$ . Finally, we set  $A_m = A_n = A$ .

The household problem is now easier. The first-subperiod value function is

$$W(m, k_m, k_n) = \frac{A}{w} (rk_m + m + p_m k_m + p_n h_n - T) + \max_{\hat{m}, \hat{k}_m, \hat{k}_n} \left\{ -\frac{A}{w} (\hat{m} + p_m \hat{k}_m + p_n \hat{k}_n) + V(\hat{m}, \hat{k}_m, \hat{k}_n) \right\}, \quad (37)$$

while the second-subperiod value function is<sup>22</sup>

$$V(\hat{m}, \hat{k}_n, \hat{k}_n) = \sigma \left[ U\left(\frac{\hat{m}}{p_c}, \hat{k}_n\right) + \beta W(0, \hat{k}_m, \hat{k}_n) \right] + (1 - \sigma) \left[ U(0, \hat{k}_n) + \beta W(\hat{m}, \hat{k}_m, \hat{k}_n) \right]. \quad (38)$$

The first-order conditions are

$$\hat{m} : \frac{A}{w} = \sigma U_1\left(\frac{\hat{m}}{p_c}, \hat{k}_n\right) \frac{1}{p_c} + (1 - \sigma) \beta \frac{A}{w'} \quad (39)$$

$$\hat{k}_m : \frac{A}{w} p_m = \beta \frac{A}{w'} (r' + p'_m) \quad (40)$$

$$\hat{k}_n : \frac{A}{w} p_n = \sigma U_2\left(\frac{\hat{m}}{p_c}, \hat{k}_n\right) + (1 - \sigma) U_2(0, \hat{k}_n) + \beta \frac{A}{w'} p'_n. \quad (41)$$

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<sup>22</sup>Here we assume that in the second subperiod you get utility from (you can use) housing purchased in the first subperiod, different from the baseline model where all investments in the period come on line one period hence. This reduces some notation, but does not actually matter for results, since  $k_n = \bar{K}_n$  is fixed in equilibrium.

In steady state, (41) implies

$$\frac{A}{w} p_n = \frac{\mathbb{E}U_2}{1 - \beta}, \quad (42)$$

where  $\mathbb{E}U_2 = \sigma U_2(c_m, \bar{K}_n) + (1 - \sigma) U_2(0, \bar{K}_n)$ , which to a housing economist should be very natural.<sup>23</sup>

Production and retail firms are as before, except that with no credit meetings we get a simplified expression for prices,

$$p_x(1 + i) = \frac{\sigma}{n} p_c. \quad (43)$$

A steady state equilibrium allocation is defined as market consumption and aggregate market work  $(c_m, L)$  satisfying feasibility and a simplified version of (39),

$$n c_m = f(L, \bar{K}_m) \quad (44)$$

$$A(i + \sigma) \frac{n}{\sigma} = \sigma U_1(c_m, \bar{K}_n) f_1(L, \bar{K}_m), \quad (45)$$

while (40) and (41) simply deliver the equilibrium prices  $p_m$  and  $p_n$ . Notice (44) and (45) are just stripped-down versions of (22)-(23). Given  $(c_m, L)$ , other variables follow easily, including  $p_c = \hat{M}/c$  and the relative price of housing, in terms of either retail or wholesale prices,

$$\frac{p_n}{p_c} = \frac{\sigma \mathbb{E}U_2(c_m, \bar{K}_n) f_1(L, \bar{K}_m)}{A(1 - \beta) n(1 + i)} \quad (46)$$

$$\frac{p_n}{p_x} = \frac{\mathbb{E}U_2 f_1(L, \bar{K}_m)}{A(1 - \beta)}. \quad (47)$$

Immediately (44)-(45) yield

$$\frac{\partial L}{\partial i} = \frac{-n^2 A}{D} < 0 \quad \text{and} \quad \frac{\partial c}{\partial i} = \frac{-n A f_1}{D} < 0,$$

where  $D = -\sigma^2 (n U_1 f_{11} + f_1^2 U_{11}) > 0$ . As always, the proximate effect of higher nominal

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<sup>23</sup>The left side of (42) is the utility cost of acquiring more housing, since  $p_n$  converts  $k_n$  into dollars,  $1/w$  converts dollars into time, and  $A$  converts time to utility. The right side is the benefit, which is the expected marginal utility from an additional unit of  $k_n$  capitalized over the (infinite) life of the asset. More generally, as (41) shows, out of steady state one also has to take into account capital gains or losses, as  $p_n/w$  may change over time.

interest or inflation rates is to reduce market consumption, since this policy is a direct tax on activities that use money, and this reduces market work in equilibrium. After some algebra, we derive

$$\frac{\partial}{\partial i} \left( \frac{p_n}{p_c} \right) = \frac{\sigma^3 f_1^3 (U_{11} \mathbb{E}U_2 - U_1 \mathbb{E}U_{21}) - (1 - \sigma) \sigma A n (n f_{11} \mathbb{E}U_2 + f_1^2 \mathbb{E}U_{21})}{A (1 - \beta) n (1 + i)^2 D}.$$

The first term in the numerator is negative if  $k_n$  is a normal good, while the second is positive as long as  $c_m$  and  $k_n$  are substitutes,  $U_{21} < 0$ . So the net effect could go either way, but note that  $\sigma = 1$  implies the second term vanishes and  $p_n/p_c$  unambiguously falls when  $i$  increases. Hence, when there are no search frictions, we get a simple result that can be understood as follows: When  $i$  increases,  $c_m$  falls and households are worse off; if  $k_n$  is normal they demand less of it, taking prices as given, but since supply is fixed at  $\bar{K}_n$ , the relative price of housing must fall so that demand meet supply. When there are search frictions,  $\sigma < 1$ , however, there is second effect that goes the other way.

By contrast, in terms of the producer rather than consumer price index, as long as  $c_m$  and  $k_n$  are substitutes we have the unambiguous result

$$\frac{\partial}{\partial i} \left( \frac{p_n}{p_x} \right) = \frac{-n (n f_{11} \mathbb{E}U_2 + f_1^2 \mathbb{E}U_{21})}{(1 - \beta) D} > 0,$$

independent of whether there are search frictions. The economic explanation in this case is that  $p_x = \sigma p_c / n(1 + i)$ , so in the retail market the markup  $p_c/p_x = (1 + i) n / \sigma$  increases lockstep with  $i$ . Since the markup increases with  $i$ , housing prices deflated by consumer prices may go down, but housing prices deflated by producer prices must go up with inflation.<sup>24</sup>

We can also deflate housing prices by the money supply, as we did in the data presentation

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<sup>24</sup>One can also look at nominal prices, and derive

$$\begin{aligned} \frac{\partial p_n}{\partial i} &= \frac{M\beta}{c_m^2 D} [(1 - \sigma) A n f_1 + \sigma^2 (f_1^2 U_1 - c_m f_1^2 U_{11} - c_m n U_1 f_{11})] \\ \frac{\partial p_x}{\partial i} &= \frac{M\beta f_1 A}{c_m^2 D}. \end{aligned}$$



in Section 2. Since in equilibrium  $p_c c_m = \hat{m} = M(1 + \pi) = M(1 + i)\beta$ , we have

$$\frac{p_n}{M} = \frac{\sigma f_1 \mathbb{E}U_2}{nA\beta(1 - \beta)c_m},$$

and after some algebra

$$\frac{\partial}{\partial i} \left( \frac{p_n}{M} \right) = -\frac{\sigma [c_m f_1^2 \mathbb{E}U_{21} + (c_m n f_{11} - f_1^2) \mathbb{E}U_2]}{\beta(1 - \beta)c_m^2 D} > 0$$

as long as  $c_m$  and  $k_n$  are substitutes. Actually, this last result should have been obvious from  $p_n/M = (\sigma/n c_m)(p_n/p_x)$ , since we already know  $c_m$  decreases and  $p_n/p_x$  increases with  $i$ . It is also obvious that

$$\frac{\partial}{\partial i} \left( \frac{p_n \bar{K}_n}{p_x x} \right) > 0,$$

since we already know  $x$  decreases and  $p_n/p_x$  increases with  $i$ .

Finally, in terms of consumer rather than producer prices, after some algebra,<sup>25</sup>

$$\begin{aligned} \frac{\partial}{\partial i} \left( \frac{p_n \bar{K}_n}{p_c c_m} \right) &= \tilde{D} \sigma^3 f_1^3 \mathbb{E}U_2 (c_m U_{11} + U_1) - \sigma^3 f_1^3 U_1 \mathbb{E}U_{21} c_m \\ &\quad - \tilde{D} (1 - \sigma) \sigma A n \left[ (n f_{11} c_m - f_1^2) \mathbb{E}U_2 + \tilde{D} c_m f_1^2 \mathbb{E}U_{21} \right]. \end{aligned}$$

where  $\tilde{D} = \bar{K}_n / A c_m^2 (1 - \beta) n (1 + i)^2 D > 0$ . The final term and the middle term are positive if  $c_m$  and  $k_n$  are substitutes, while the first term is positive iff  $-c_m U_{11} < U_1$ . Hence, although it is not unambiguous, in general, as long as households are not too risk averse we have

$$\frac{\partial}{\partial i} \left( \frac{p_n \bar{K}_n}{p_c c_m} \right) > 0.$$

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<sup>25</sup>We have

$$\begin{aligned} \frac{\partial}{\partial i} \left( \frac{p_n \bar{K}_n}{p_c c_m} \right) &= \frac{\bar{K}_n}{c_m} \frac{\partial}{\partial i} \left( \frac{p_n}{p_c} \right) + \bar{K}_n \left( \frac{p_n}{p_c} \right) \frac{\partial}{\partial i} \frac{1}{c_m} \\ &= \frac{\bar{K}_n}{c_m^2} \frac{[\sigma^3 f_1^3 (U_{11} \mathbb{E}U_2 - U_1 \mathbb{E}U_{21}) - (1 - \sigma) \sigma A n (n f_{11} \mathbb{E}U_2 + f_1^2 \mathbb{E}U_{21})] c_m}{A(1 - \beta) n (1 + i)^2 D} \\ &\quad + \bar{K}_n \frac{1}{c_m^2 D} \frac{\sigma^3 \mathbb{E}U_2 f_1^3 U_1 + \sigma (1 - \sigma) \mathbb{E}U_2 f_1^2 A n}{A(1 - \beta) n (1 + i)^2} \end{aligned}$$

which simplifies to the expression in the text.

Note that since  $\bar{K}_n$  is constant, the last two results also imply that price of housing relative to GDP will also have the same properties.

We summarize these findings as:

**Proposition 1** *In the model of this section, we have the following results:*

1.  $\frac{\partial L}{\partial i} < 0$  and  $\frac{\partial c_m}{\partial i} < 0$ .
2.  $\frac{\partial}{\partial i} \left( \frac{p_n}{p_c} \right) < 0$  if  $k_n$  is a normal good and  $\sigma = 1$ ; if  $\sigma < 1$  the sign is ambiguous.
3.  $\frac{\partial}{\partial i} \left( \frac{p_n}{p_x} \right) > 0$  iff  $U_{12} < 0$ .
4.  $\frac{\partial}{\partial i} \left( \frac{p_n \bar{K}_n}{M} \right) > 0$  if  $U_{12} < 0$ .
5.  $\frac{\partial}{\partial i} \left( \frac{p_n \bar{K}_n}{p_x x} \right) = \frac{\partial}{\partial i} \left( \frac{p_n}{p_x x} \right) > 0$  if  $U_{12} < 0$ .
6.  $\frac{\partial}{\partial i} \left( \frac{p_n \bar{K}_n}{p_c c_m} \right) = \frac{\partial}{\partial i} \left( \frac{p_n}{p_c c_m} \right) > 0$  if  $U_{12} < 0$  and  $-c_m U_{11}/U_1$  is not too big.

In the quantitative work, in the next section, we are most interested in the effects of  $i$  on the value of housing relative to either GDP or  $M$ , but we feel obliged to comment at this point on the effect of  $i$  on  $p_n/p_c$ . As one has to believe that housing is a normal good, Result 2 in Proposition 1, especially when there are no search frictions, seems to contradict the idea one may have *thought* we were pushing in the Introduction, that inflation should necessarily raise the relative price  $p_n/p_c$ . It turns out that this is *not* what theory predicts. To clarify, note that the result  $\partial(p_n/p_c)/\partial i < 0$  is really pretty obvious from basic undergraduate micro: when  $i$  increases,  $c_m$  falls by Result 2, and households are worse off; as long as  $k_n$  is a normal good, demand for  $k_n$  falls, and so does its relative price, at least if there are no search frictions in the sense that  $\sigma = 1$  (while if  $\sigma < 1$  there is second effect that goes the other way). Basic theory does *not* predict that higher inflation, or equivalently higher nominal interest rates or

money growth rates, should raise the price of housing relative to retail-market consumption goods.

Interestingly, however, if we use wholesale rather than retail prices in the denominator in defining relative prices, we get  $\partial(p_n/p_x)/i > 0$  unambiguously, whether or not there are search frictions, at least as long as market and home goods are substitutes as we believe they are based on both introspection and empirical evidence.<sup>26</sup> To paraphrase the explanation given above, since the retail markup  $p_c/p_x = (1+i)n/\sigma$  increases with  $i$ ,  $p_n/p_x$  can go up even if  $p_n/p_c$  goes down with inflation. Moreover, the value of the housing stock  $p_n\bar{K}_n$  scaled by expenditure  $p_x x$  also rises with inflation, as long as home and market goods are substitutes, as does  $p_n\bar{K}_n$  scaled by  $p_c c_m$  at least when risk aversion is not too big. And the value of the housing stock  $p_n\bar{K}_n$  scaled by  $M$  also rises with inflation as long as home and market goods are substitutes. We think it is really quite remarkable that one can derive such strong theoretical predictions with very few restrictions on parameters or functional forms, although we admittedly simplify the problem in this section by assuming no investment, and as always we maintain quasi-linearity, where  $\ell_n$  and  $k_n$  enter period utility linearly.

Still, these are strong results, and form the basis for the general notion that inflation or nominal interest rates affect the housing market and the economy as a whole as described in the Introduction. Of course, one wants to know how big these effects might be. Before proceeding to quantitative work, however, we briefly mention that the analytic results in Proposition 1 can be generalized to some extent, although we have not tried to do this with the full model where the allocation is summarized by the 10 equation system (22)-(31) (for that we rely on numerical analysis). One relatively straightforward extension is to drop the assumption that households get utility directly from  $k_n$ , but use it as an input into home production  $c_n = g(\ell_n, k_n)$ , as in the general model, still abstracting from investment. We

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<sup>26</sup>As we discuss in the next section, estimates of the substitutability of home and market goods based on micro and macro data can be found in Rupert et al. (1995) and McGrattan et al. (1997), respectively, both of which imply they are substitutes.

now briefly sketch this, for ease of presentation setting  $\sigma = n = 1$  and we revert back to two different disutility parameter for labor.

The first-subperiod value function is again given by (37). Since  $\sigma = 1$ , so the second-subperiod value function is given by a simplified version of (38),

$$V(\hat{m}, \hat{k}_m, \hat{k}_n) = \max_{\ell_n} \left\{ u \left[ \frac{\hat{m}}{p_c}, g(\ell_n, k_n) \right] - A_n \ell_n + \beta W(0, \hat{k}_m, \hat{k}_n) \right\}.$$

Furthermore, since  $\sigma = 1$ , there is only one event in the second subperiod, so  $c_m$  is always  $\hat{m}/p_c$  and there is only one choice of  $\ell_n$  and  $c_n = g(\ell_n, k_n)$  (as opposed to the case where  $\sigma_2$  and  $\sigma_0$  are positive, where there are three). Then, emulating the above analysis, it is easy to reduce the steady state condition to two equations in time use  $(\ell_m, \ell_n)$ :

$$\begin{aligned} (1+i)A_m &= U_1 [f(\ell_m, \bar{K}_m), g(\ell_n, \bar{K}_n)] f_1(\ell_m, \bar{K}_m) \\ A_n &= U_2 [f(\ell_m, \bar{K}_m), g(\ell_n, \bar{K}_n)] g_1(\ell_m, \bar{K}_n). \end{aligned}$$

This rather elegant reduction highlights the near-perfect symmetry between home and market activity. Symmetry is only broken by the fact that, as one can plainly see,  $i > 0$  distorts the market allocation directly (which then distorts the nonmarket allocation in equilibrium). From this system one can derive

$$\frac{\partial \ell_m}{\partial i} = \frac{A_m (g_{11}U_2 + g_1^2 U_{22})}{\hat{D}} \quad \text{and} \quad \frac{\partial \ell_n}{\partial i} = \frac{-A_m f_1 g_1 U_{21}}{\hat{D}},$$

where  $\hat{D} = f_{11}g_{11}U_1U_2 + f_1^2g_{11}U_2U_{11} + g_1^2f_{11}U_1U_{22} + f_1^2g_1^2(U_{11}U_{22} - U_{12}^2) > 0$ . Therefore  $\ell_m$  and hence  $c_m$  decrease with  $i$ , while  $\ell_n$  and  $c_n$  increase with  $i$  if and only if  $U_{21} < 0$  ( $c_m$  and  $c_n$  are substitutes). After some tedious algebra, the effect of  $i$  on  $p_n/p_c$  remains ambiguous, although one can find conditions to make it negative, as in the simpler model, e.g.,  $c_m$  normal and  $g_{21}U_{12} > 0$ , although the latter is not particularly natural since we tend to think that  $\ell_n$  and  $k_n$  are compliments in production so that  $g_{21} > 0$ , while  $c_m$  and  $c_n$  are substitutes in consumption so that  $U_{12} < 0$ .

Similarly, one can show

$$\frac{\partial}{\partial i} \left( \frac{p_n}{p_x} \right) = \frac{U_{21} f_1^2 U_2 (g_2 g_{11} - g_1 g_{21}) + U_2 g_2 f_{11} (g_{11} U_2 + g_1^2 U_{22})}{(1 - \beta) \hat{D}} > 0$$

in the natural case where  $c_m$  and  $c_n$  are substitutes and  $\ell_n$  and  $k_n$  are compliments. In terms of deflating by  $M$ , note the following:  $M = M' / (1 + \pi) = p_c c_m / (1 + \pi) = p_x x / \beta$ , using the markup condition  $p_c = (1 + i) p_x$  and the Fisher Equation. Hence  $p_n / M = \beta p_n / p_x x$ . We have already established that under natural conditions  $p_n / p_x$  increases, and  $x = c_m$  always decreases with  $i$ , and therefore

$$\frac{\partial}{\partial i} \left( \frac{p_n}{M} \right) > 0.$$

Again, perhaps remarkably, the theory generates very strong theoretical predictions at least when there is no investment. While more could potentially be done, we leave analytic derivation for now, and return to the general model, with investment in market and residential capital, to pursue the quantitative investigation.

## 6 Quantitative Analysis

Having demonstrated that a simple model is capable of delivering the qualitative relationships seen in the data, in this section we calibrate and solve the model to assess its quantitative implications. This requires picking functional forms, calibrating parameter values, and solving for equilibrium numerically.

### 6.1 Functional Forms

As is fairly standard, the market production function is  $f(L, k_m) = L^{\chi_m} k_m^{1-\chi_m}$  and the home production function  $g(\ell_n, k_n) = \ell_n^{\chi_n} k_n^{1-\chi_n}$ . In terms of the production of homes, we assume residential structures and land are combined to create housing according to  $h(k_s, k_l) = k_s^{\chi_h} k_l^{1-\chi_h}$ . As is also standard, we use log utility over a composite good  $C$ . The aggregator  $C$  uses the constant elasticity of substitution specification

$$C \equiv (c_m^\omega + c_n^\omega)^{\frac{1}{\omega}}, \quad (48)$$

where  $1/1 - \omega$  is the elasticity of substitution between home and market consumption.<sup>27</sup>

### 6.2 Calibration

We follow the calibration strategy: use long-run averages to calibrate as many parameters as we can, and use the properties of money demand, especially its slope, to calibrate the rest. Our calibration targets include several standard real ones from the macro literature, as well as some monetary and housing-related targets. Unless otherwise noted, our targets are computed using the data outlined in Section 2 for the period 1975-1999. To begin, we set risk aversion to  $\gamma = 1$ . The length of a period is a quarter, which means households visit the retail market 4 times a year. The average inflation rate and the average 3-month T-bill rate in our sample are 4.13% and 6.80% which yields  $\beta = 0.993$  and  $\mu = 0.033$ . The key

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<sup>27</sup>One could introduce weights in front of  $c_m$  and  $c_n$  but given that we have market-specific disutility of labor,  $A_m$  and  $A_n$ , doing this would only change units and will not change the results.

elasticity parameter  $\omega$  is set to  $\omega = 0.4$  in the benchmark calibration based on estimates in Rupert et al. (1995) and McGrattan et al. (1997), using micro and macro, respectively. We show results for a range of values between 0.4 and 0.8, which is the value used in Benhabib et al. (1991). While we use  $\omega = 0.4$  as our benchmark, since one of the underlying variables, home production, cannot be exactly measured, it should be understood that there is a lot of uncertainty about the value of this parameter. Some parameters can be set directly using long-run averages. Thus,  $\chi_h = 0.73$  is set to match the value of residential structures plus durables relative to in the data to housing capital in the model. It turns out the the data lead us to set both  $\delta_m$  and  $\delta_s$  to 0.015 (a 6% annual depreciation). Since it only affects scales, we normalize  $k_l = 1$ .

This leaves the parameters  $(A_m, A_n, \chi_m, \chi_n, n, \sigma_1, \sigma_2)$  free. We use these to jointly match the following seven targets. As is standard in the home production literature, we target the observations that households spend on average  $L_m = 33\%$  of their discretionary time working in the market and  $L_n = 25\%$  working at home where the latter is the average across three types of agents. The ratio of market capital to output,  $k_m/y$  and housing capital to output,  $k_n/y$  are 2.07 and 1.95, respectively at an annual frequency, where  $y$  refers to GDP. As explained earlier, we use the production definition of GDP from the model. We use an average retail markup of 30% as reported in Faig and Jerez (2005). Finally, we match the level of slope of money demand using average annual velocity of 5.764 and semi-elasticity of velocity with respect to the interest rate of 0.0256, both of which are computed using *M1S*.<sup>28</sup> While all seven of these parameters are jointly calibrated, heuristically  $A_m$  and  $A_n$  help match the targets for hours,  $\chi_m$  and  $\chi_n$  help match the two capital-to-output ratios,  $n$  helps match the markup,  $\sigma_2$  help match the level of velocity and  $\sigma_1$  helps match the elasticity of money demand (or its inverse, velocity). Our benchmark calibration yields  $A_m = 1.48$ ,

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<sup>28</sup>The latter is a standard measure used in monetary economics going back to Lucas (2000) and earlier. It corresponds to the elasticity of money demand with respect to the interest rate when the elasticity with respect to income is unity. See also Aruoba, Waller and Wright (2011).

$A_n = 1.76$ ,  $\chi_m = 0.82$ ,  $\chi_n = 0.88$ ,  $n = 1.24$ ,  $\sigma_1 = 0.07$  and  $\sigma_2 = 0.90$ .<sup>29</sup>

### 6.3 Results

Given the parameters from the benchmark calibration, standard methods allow us to easily solve for equilibrium numerically. We compute the steady state of the model for each annual value of 3-month T-bill rate observed in the sample 1975-1999. We then compare the key variables from the model with their data counterparts. Table 2 reports the key results from this exercise for the benchmark calibration and various alternative calibrations we turn to below. Under the benchmark calibration the semi-elasticity of  $k_n/M$  with respect to the interest rate is 0.028. Our results in Section 2 showed that the same elasticity is 0.037 in the data, while the semi-elasticity of  $k_n/M$  with respect to inflation – the same number in the model – is 0.026 in the data. On the other hand, the semi-elasticity of  $k_n/y$  with respect to inflation or interest rate in the model is very small, 0.0002, while it is 0.011 in the data. Obviously our goal in this section is not to match these numbers exactly – our model is too simple to ask for that. However, we find it reassuring that our model delivers a semi-elasticity for  $k_n/M$  in the same ballpark as the data and the semi-elasticity for  $k_n/y$  is smaller in magnitude than the one for  $k_n/M$ , as it is in the data, based on the assumption that changes in monetary policy were the underlying impulse.

The rest of Table 2 shows the results of various alternative calibrations. First, columns 2 through 5 show how the results change as  $\omega$  changes from approximately 0 to 0.8, or the elasticity of substitution between market and nonmarket goods change between 1 to 5. Focusing on column 5 with  $\omega = 0.8$ , we see that the elasticity of  $k_n/y$  is now 0.007, a value much closer to the data. Accordingly, the elasticity for  $k_n/M$  is also slightly higher and closer to the value in the data. Figures 15 and 16 shows the model-predicted values and the actual data for the calibrations in columns 1 through 5.

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<sup>29</sup>Note that this calibration implies 3% of retailers are unable to match with a consumer (and thus their goods go unsold) and about 8% of retail transactions are conducted using money.



Column 6 of Table 2 uses a monthly calibration frequency, adjusting all variables appropriately. While the calibrated parameters change, naturally, the results are by and large identical to the benchmark calibration. Similarly, column 7 uses the expenditure definition of GDP and once again results are not affected.

Finally, column 8 uses a different strategy in a few dimensions. First, the calibration frequency is annual. Second, we drop the average velocity as a target. Instead, we use the evidence in Klee (2008) that about 34% of retail transactions (in value) are done using cash. Accordingly, we impose  $\sigma_1/\sigma_2 = 0.34/0.66$ . This calibration yields results that are remarkably good. The elasticities of  $k_n/y$  and  $k_n/M$  are now 0.014 and 0.040, respectively both which are slightly larger than their data counterparts. Of course, since we do not match velocity, it comes at 0.63, about one tenth of the value for *M1S*. From this table, we conclude that while there are trade-offs, our model is able to deliver results that are qualitatively in line with the data.

## 7 Conclusion

We document very strong evidence for the “conventional wisdom” that housing is a good hedge against inflation. We do this by showing that there is a positive relationship between aggregate value of housing, scaled by either GDP or the money stock and inflation for the U.S. using four different data sources. We also show house prices relative to GDP also has a positive relationship with inflation for thirteen advanced economies.

We then asked, what kind of theory might help account for these facts? Obviously one needs a theory with housing front and center, and what better class of models could one use than those that take seriously the role of home production and production of homes? Equally obviously, one should want a model where the role of money, and hence the effects of money growth, inflation and interest rates, are taken seriously by trying to model explicitly the role of money and related assets in the exchange process.

To reiterate the salient economic idea, in retrospect, after having seen the data and the theory, here is our argument. As long as money is used in at least some market transactions, inflation is a tax on market activity, leading to substitution out of market and into household activity. This has some obvious general effects on the market – e.g., Proposition 1 shows, in a simplified version of the framework, that inflation unambiguously reduces market consumption and employment. How this impacts on home production generally is complicated, but intuitively one might think it leads to an increase in both the time and capital used in this activity. As Proposition 1 further shows, there are some perhaps surprisingly clear analytic predictions of the theory, but not all may be what one expected. For instance, we can prove that the price of housing relative to a retail price index is actually likely to fall with inflation, and must fall with inflation if there are no search frictions, but the price of housing relative to a wholesale price unambiguously rises with inflation as long as home and market goods are substitutes. And the value of the housing stock relative to either GDP or M also unambiguously rises with inflation under similar conditions.

So it is clear that this kind of theory can be used to organize our thinking about these observations generally. To see how big the effects might be, we also presented some quantitative analysis in a calibrated version of the model. Overall, the theory seems to work well in terms of describing the data, in the sense that it can account for a sizable fraction of the observations on movements in  $k_n/y$  and especially  $k_n/M$  taking changes in inflation or interest rates as the driving force. There is of course much more to be done in terms of trying to match other observations, like those concerning market rather than home capital, as well as looking at more data, including data from other countries. One can also begin to apply the framework – which we think is quite novel, despite being grounded on much received wisdom in macro, labor and monetary economics – where a variety of other economic ideas can be scrutinized, evaluated and tested, and we look forward to future work along these lines.

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Table 1

Comparison of Growth in Shiller HPI  
to Growth in the Average Price and Quantity of Housing Units  
(computed from the Decennial Census of Housing)

Decade	Total Percent Growth			
	Shiller HPI	Avg. Price (DCH)	Housing Units (DCH)	Nominal GDP
	(1)	(2)	(3)	(4)
1950-1960	30.1	45.2	31.1	74.9
1960-1970	28.9	49.1	24.7	97.8
1970-1980	118.3	188.6	27.3	166.6
1980-1990	71.2	93.4	12.8	106.1
1990-2000	35.3	41.2	14.9	71.5

**Table 2: Robustness of Results**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
<b>Calibrated Parameters</b>									
$A_m$	1.48	1.45	1.46	1.50	1.52	0.71	1.48	0.74	
$A_n$	1.76	1.82	1.79	1.74	1.71	2.93	1.75	2.78	
$\chi_m$	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	
$\chi_n$	0.88	0.88	0.88	0.87	0.87	0.96	0.87	0.96	
$\sigma_1$	0.07	0.07	0.07	0.07	0.07	0.02	0.07	0.14	
$\sigma_2$	0.90	0.90	0.90	0.90	0.91	0.30	0.90	0.28	
$n$	1.24	1.24	1.24	1.24	1.24	0.42	1.24	0.51	
<b>Key Implications</b>									
<b>Data</b>									
$elas(k_n/y, i)$	0.011	0.002	0.002	0.002	0.004	0.007	0.002	0.001	0.014
$elas(k_n/M, i)$	0.037	0.028	0.027	0.027	0.029	0.032	0.027	0.026	0.040

- (1) Benchmark
- (2)  $\omega \approx 0$
- (3)  $\omega = 0.2$
- (4)  $\omega = 0.6$
- (5)  $\omega = 0.8$
- (6) Monthly calibration
- (7) Expenditure definition for GDP
- (8) Annual calibration where average velocity is not targeted

Figure 1

Davis-Heathcote based Home Capital to GDP (1975-2009)

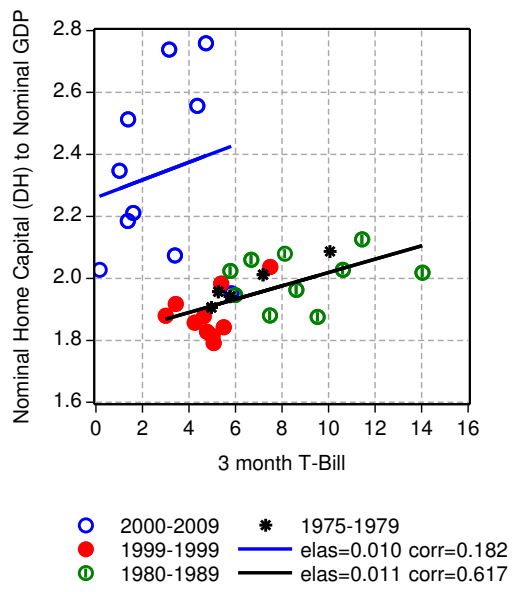
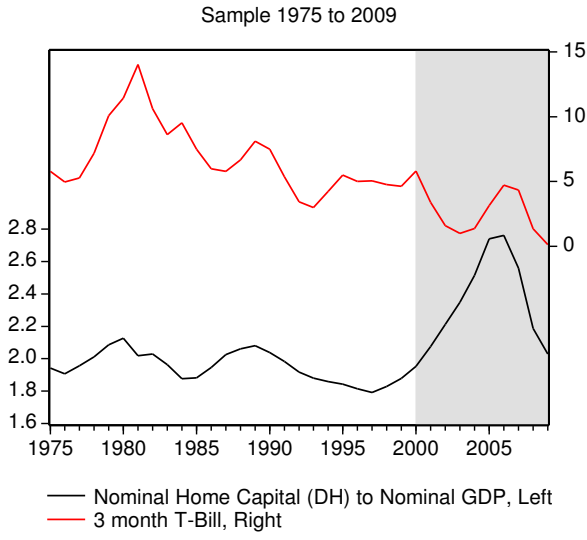
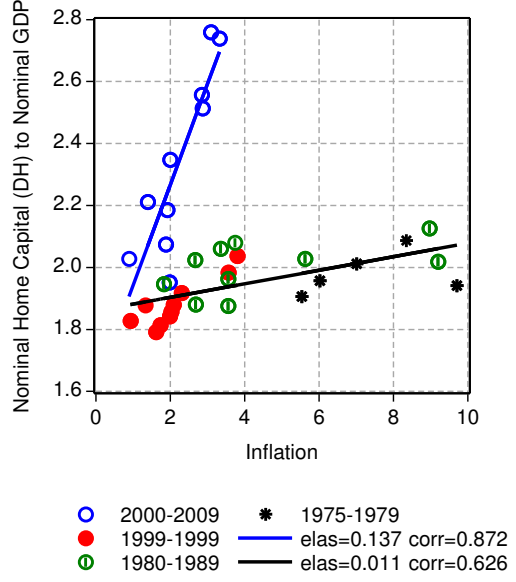
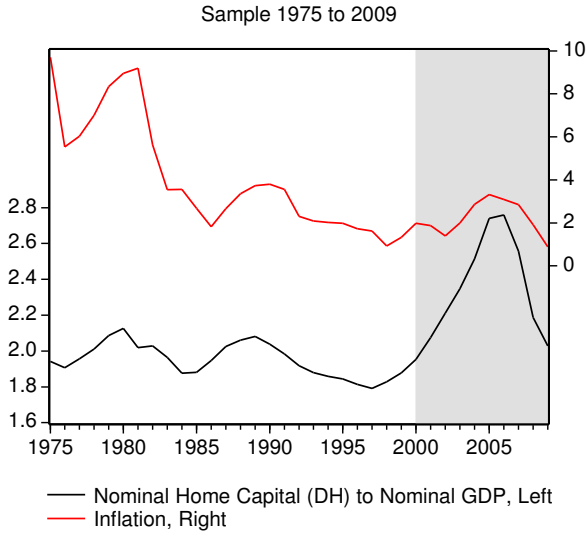


Figure 2

Davis-Heathcote based Home Capital to M1 (1975-2009)

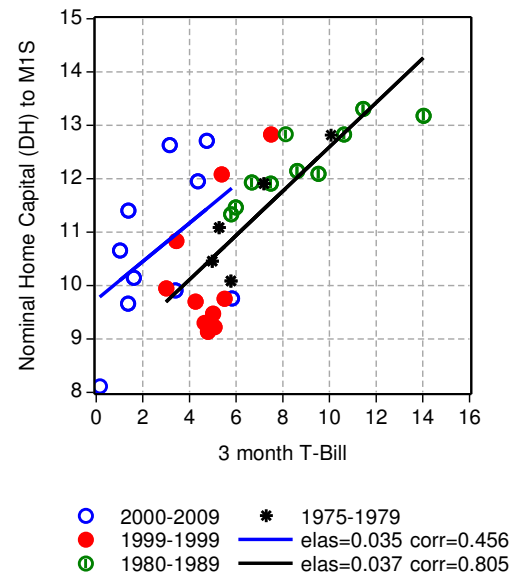
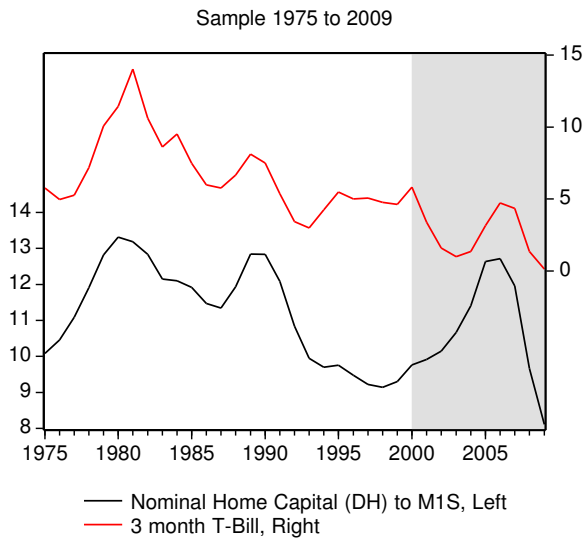
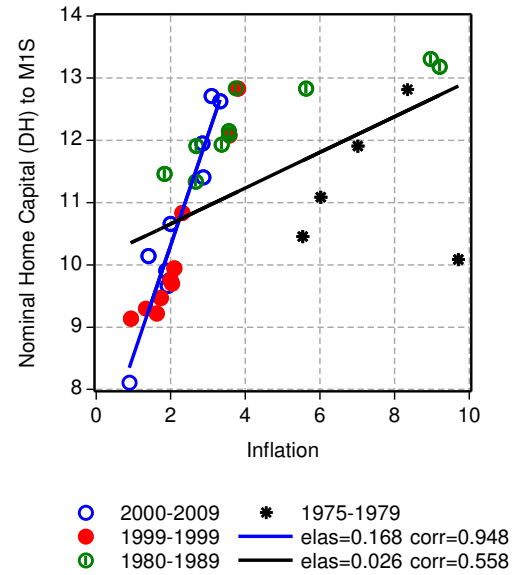
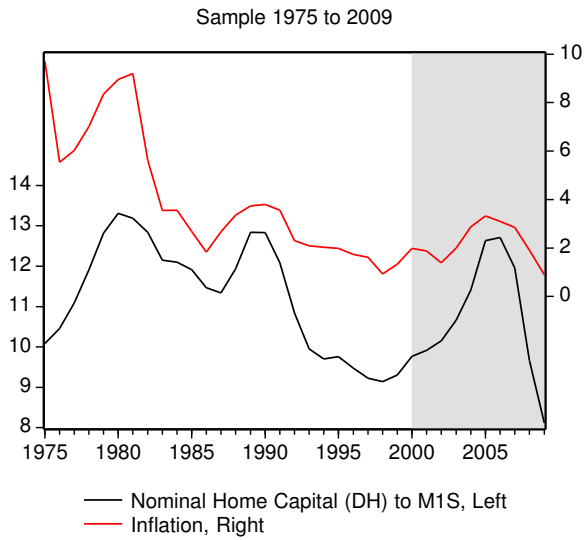
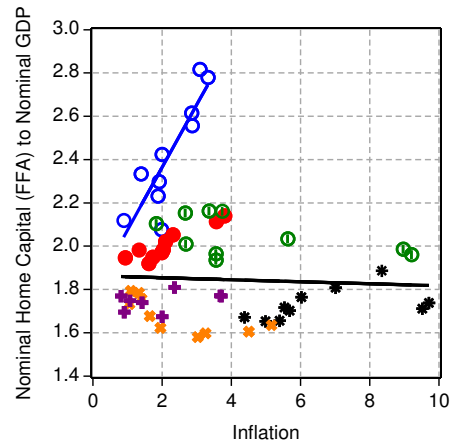
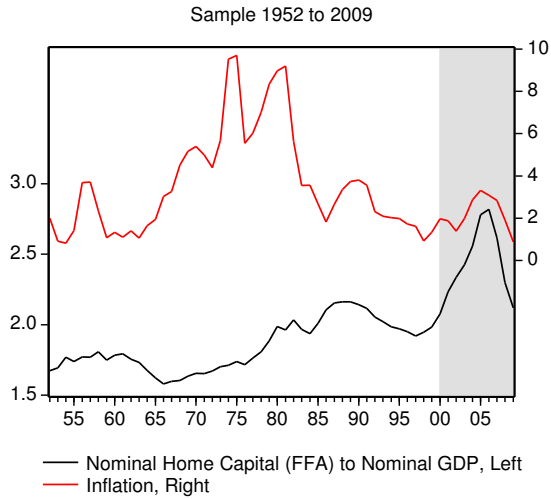
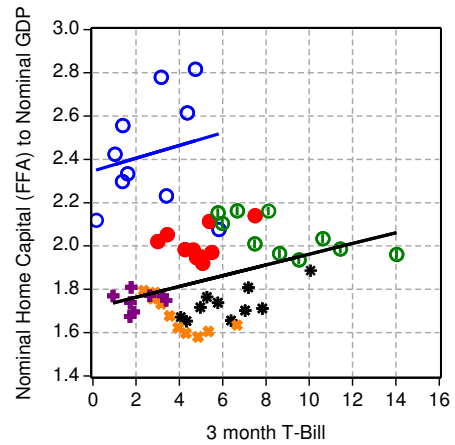
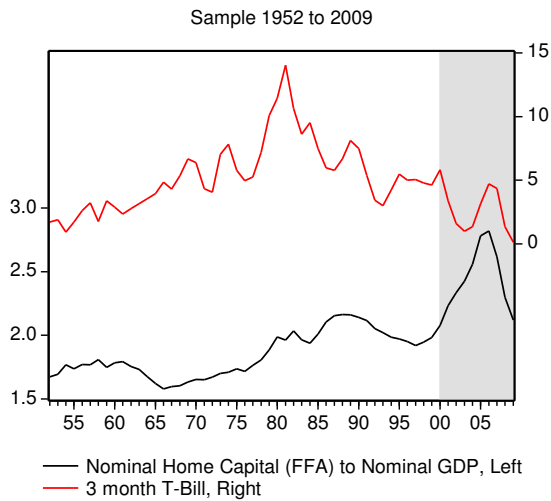


Figure 3

Flow of Funds based Home Capital to GDP (1952-2009)



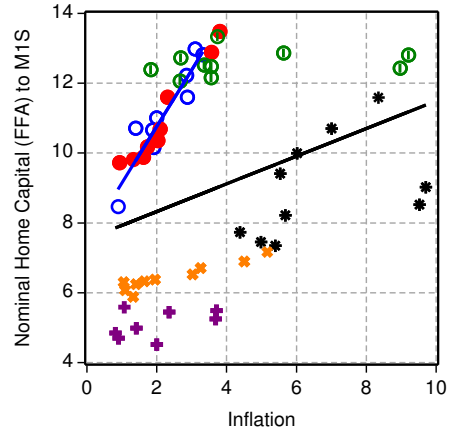
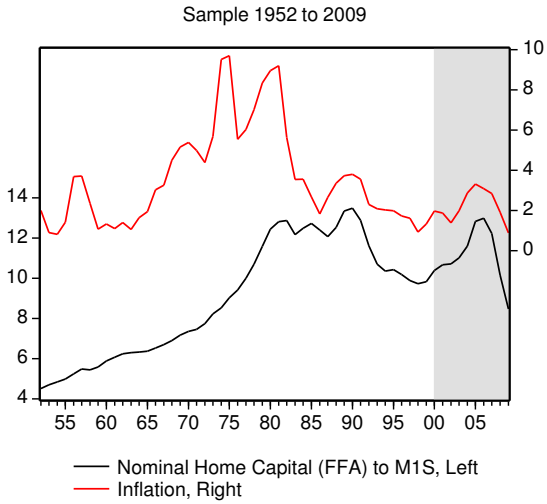
○ 2000-2009   \* 1970-1979   — elas=0.118 corr=0.874  
● 1999-1999   \* 1960-1969   — elas=-0.002 corr=-0.066  
○ 1980-1989   \* 1952-1959



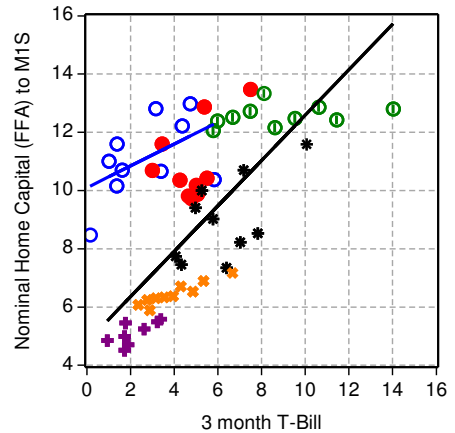
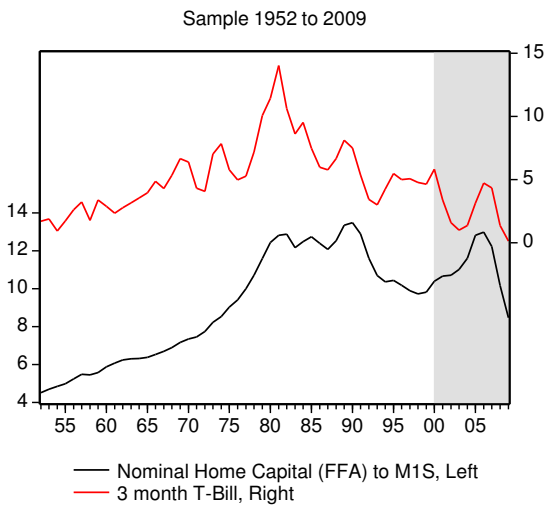
○ 2000-2009   \* 1970-1979   — elas=0.011 corr=0.212  
● 1999-1999   \* 1960-1969   — elas=0.013 corr=0.396  
○ 1980-1989   \* 1952-1959

Figure 4

Flow of Funds based Home Capital to M1 (1952-2009)



○ 2000-2009   \* 1970-1979   — elas=0.149 corr=0.936  
● 1999-1999   \* 1960-1969   — elas=0.051 corr=0.341  
○ 1980-1989   \* 1952-1959

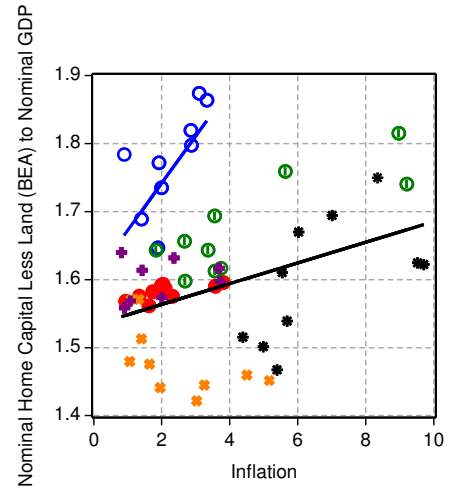
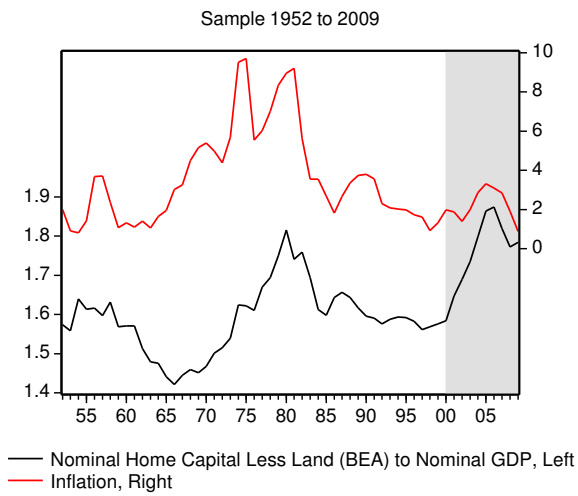


○ 2000-2009   \* 1970-1979   — elas=0.035 corr=0.516  
● 1999-1999   \* 1960-1969   — elas=0.092 corr=0.748  
○ 1980-1989   \* 1952-1959

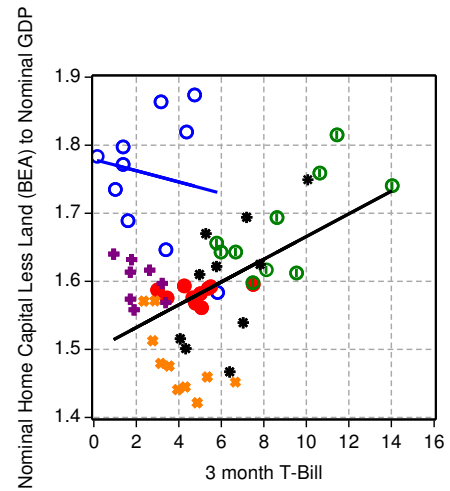
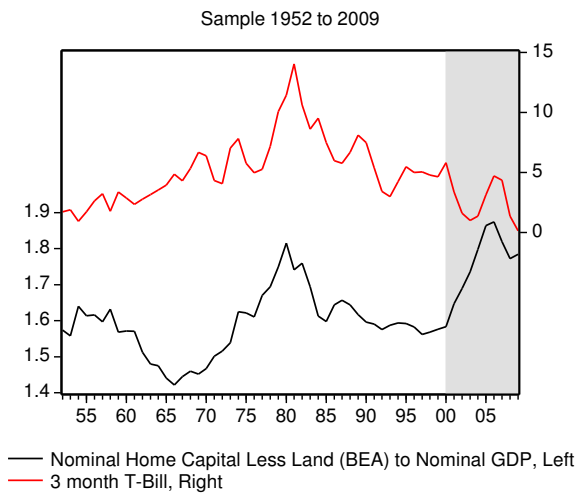


Figure 5

Bureau of Economic Activity based Home Capital to GDP (1952-2009)



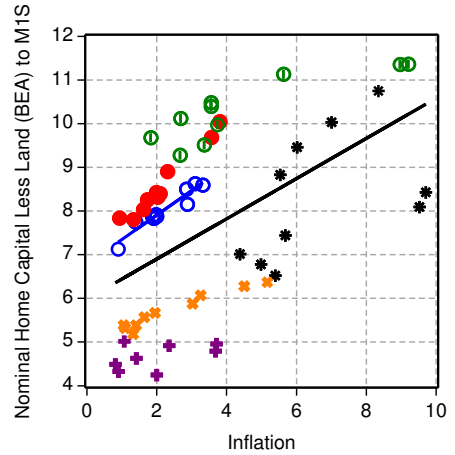
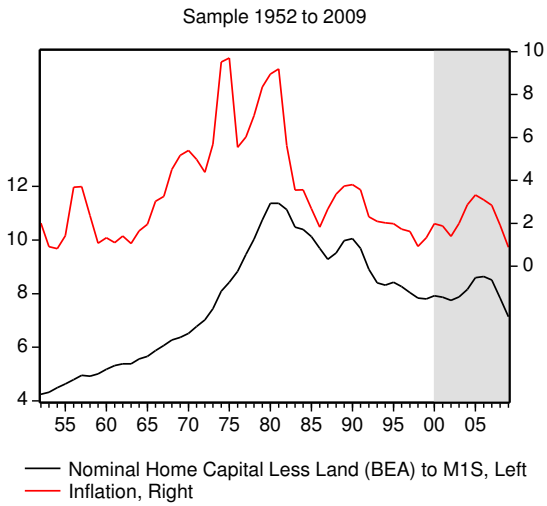
- 2000-2009      \* 1970-1979      — elas=0.039 corr=0.582
- 1999-1999      \* 1960-1969      — elas=0.009 corr=0.437
- 1980-1989      \* 1952-1959



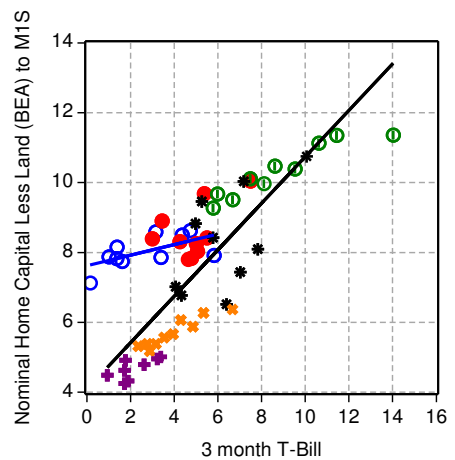
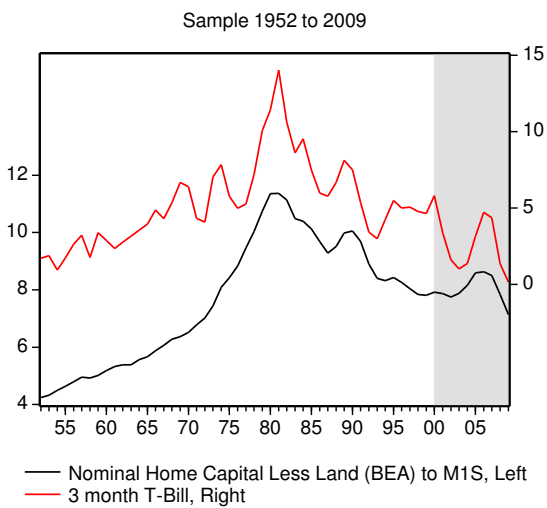
- 2000-2009      \* 1970-1979      — elas=-0.005 corr=-0.165
- 1999-1999      \* 1960-1969      — elas=0.010 corr=0.535
- 1980-1989      \* 1952-1959

Figure 6

Bureau of Economic Activity based Home Capital to M1 (1952-2009)



- 2000-2009      \* 1970-1979      — elas=0.071 corr=0.961
- 1999-1999      \* 1960-1969      — elas=0.062 corr=0.521
- 1980-1989      \* 1952-1959

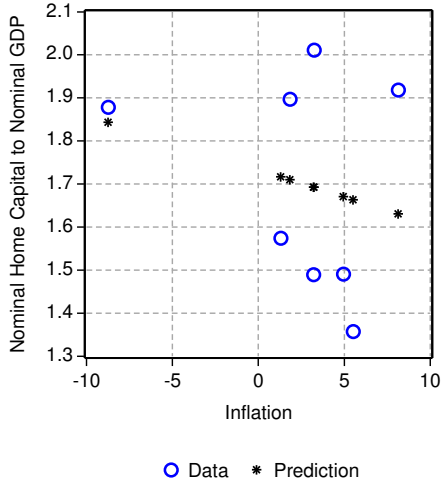


- 2000-2009      \* 1970-1979      — elas=0.019 corr=0.614
- 1999-1999      \* 1960-1969      — elas=0.089 corr=0.839
- 1980-1989      \* 1952-1959

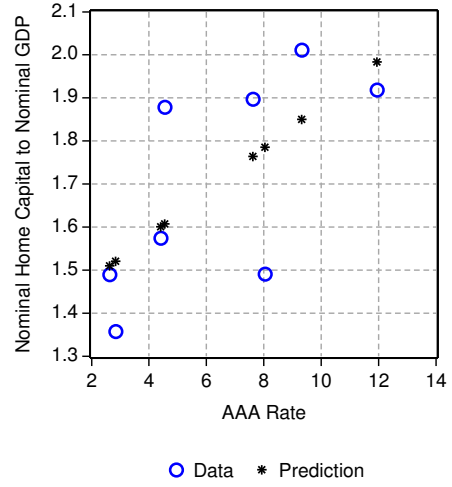
Figure 7

Decennial Census based Home Capital to GDP and to M1 (1930-2000)

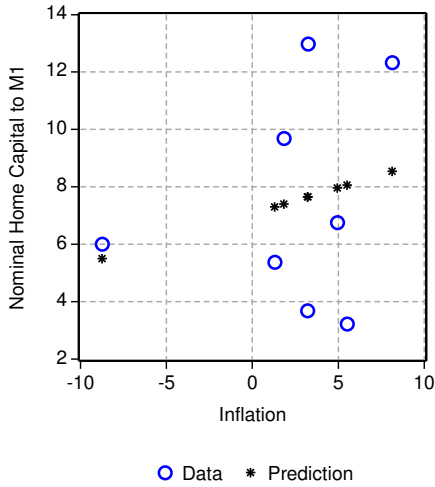
Sample 1930 to 2000 by Decade, Semi Elast = -0.008, Correl = -0.253



Sample 1930 to 2000 by Decade, Semi Elast = 0.030, Correl = 0.678



Sample 1930 to 2000 by Decade, Semi Elast = 0.015, Correl = 0.241



Sample 1930 to 2000 by Decade, Semi Elast = 0.145, Correl = 0.925

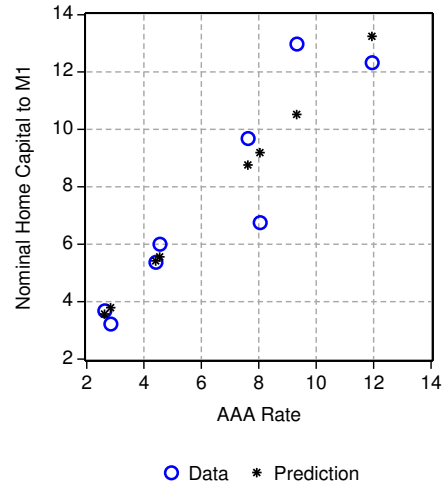
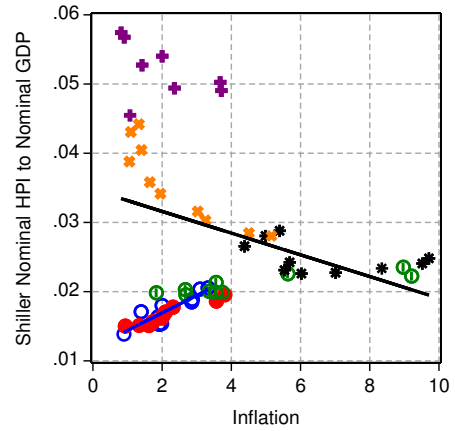
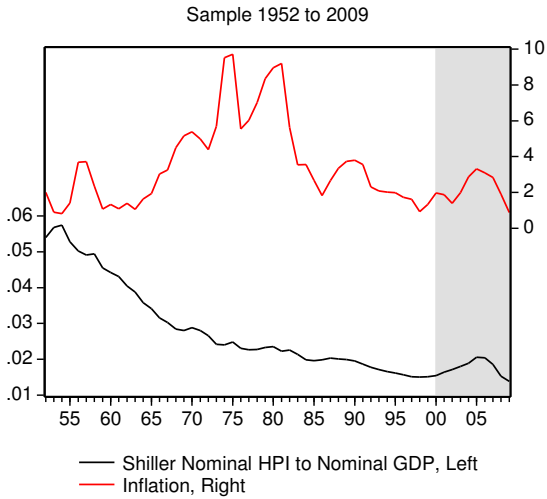
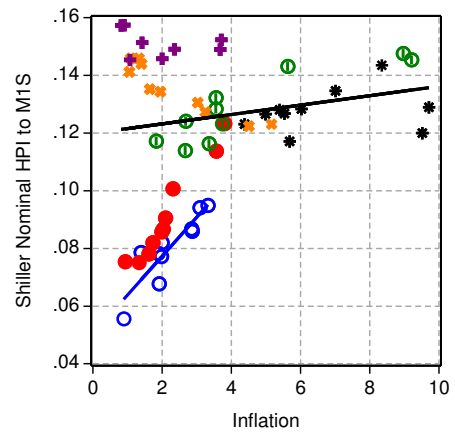
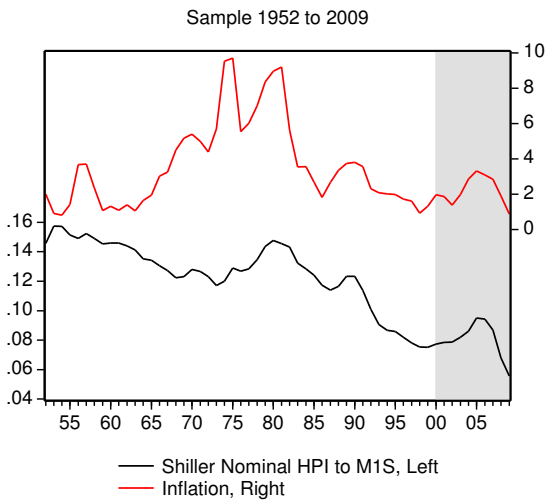


Figure 8

Ratio of Shiller HPI to GDP and to M1S (1952-2009)



○ 2000-2009   \* 1970-1979   — elas=0.146 corr=0.890  
● 1999-1999   \* 1960-1969   — elas=-0.035 corr=-0.308  
○ 1980-1989   \* 1952-1959



○ 2000-2009   \* 1970-1979   — elas=0.177 corr=0.894  
● 1999-1999   \* 1960-1969   — elas=0.018 corr=0.182  
○ 1980-1989   \* 1952-1959

Figure 9

Ratio of HPI to GDP: Belgium, France, Ireland

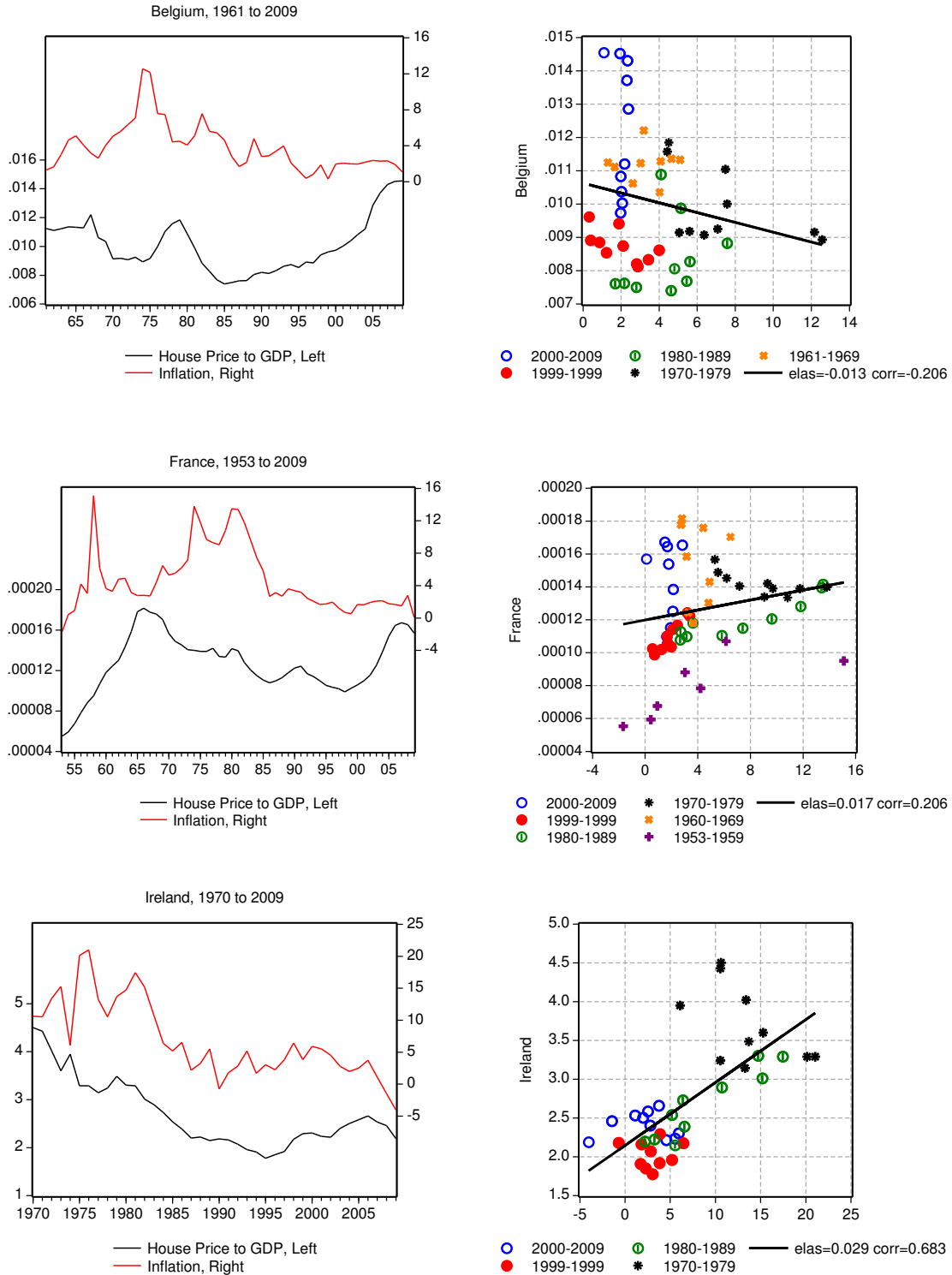


Figure 10

Ratio of HPI to GDP: Switzerland and United Kingdom

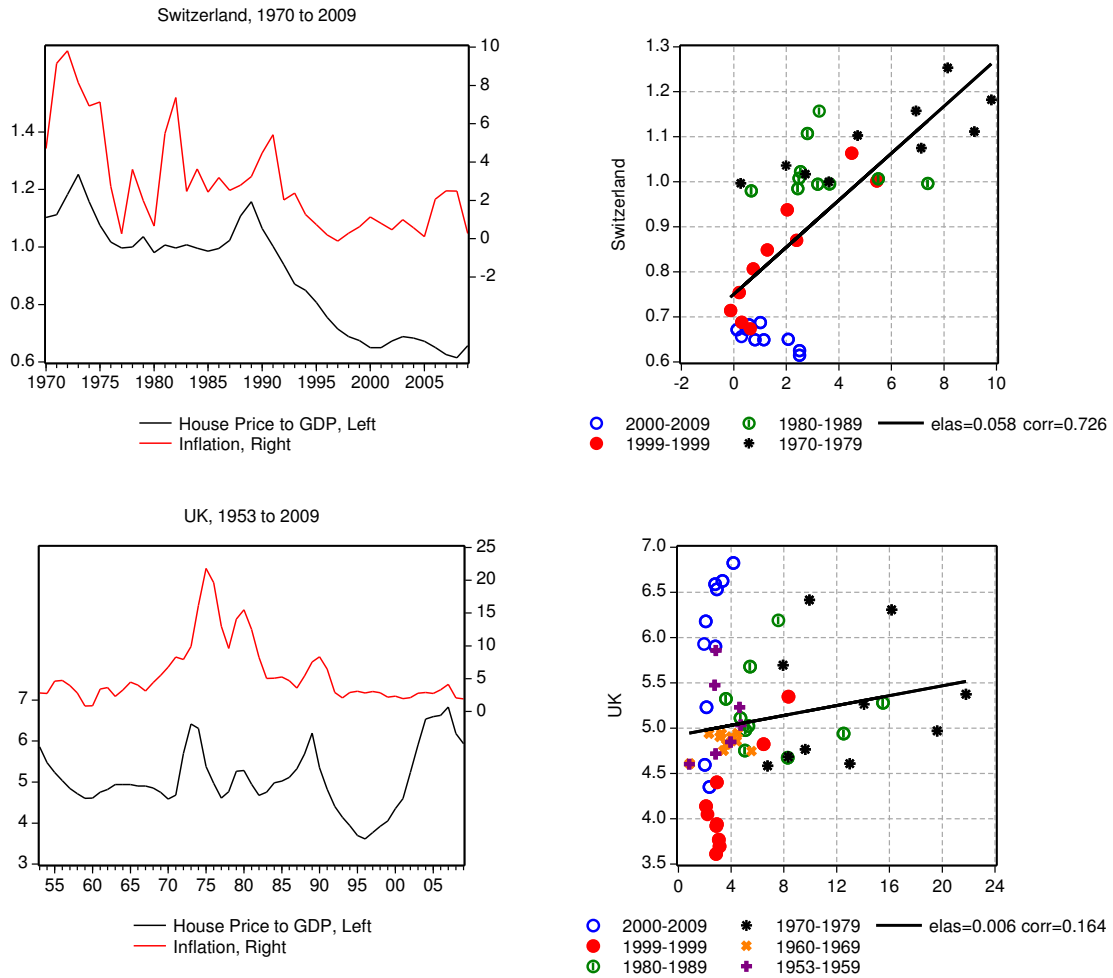


Figure 11

Ratio of HPI to GDP: Australia, Canada, Denmark

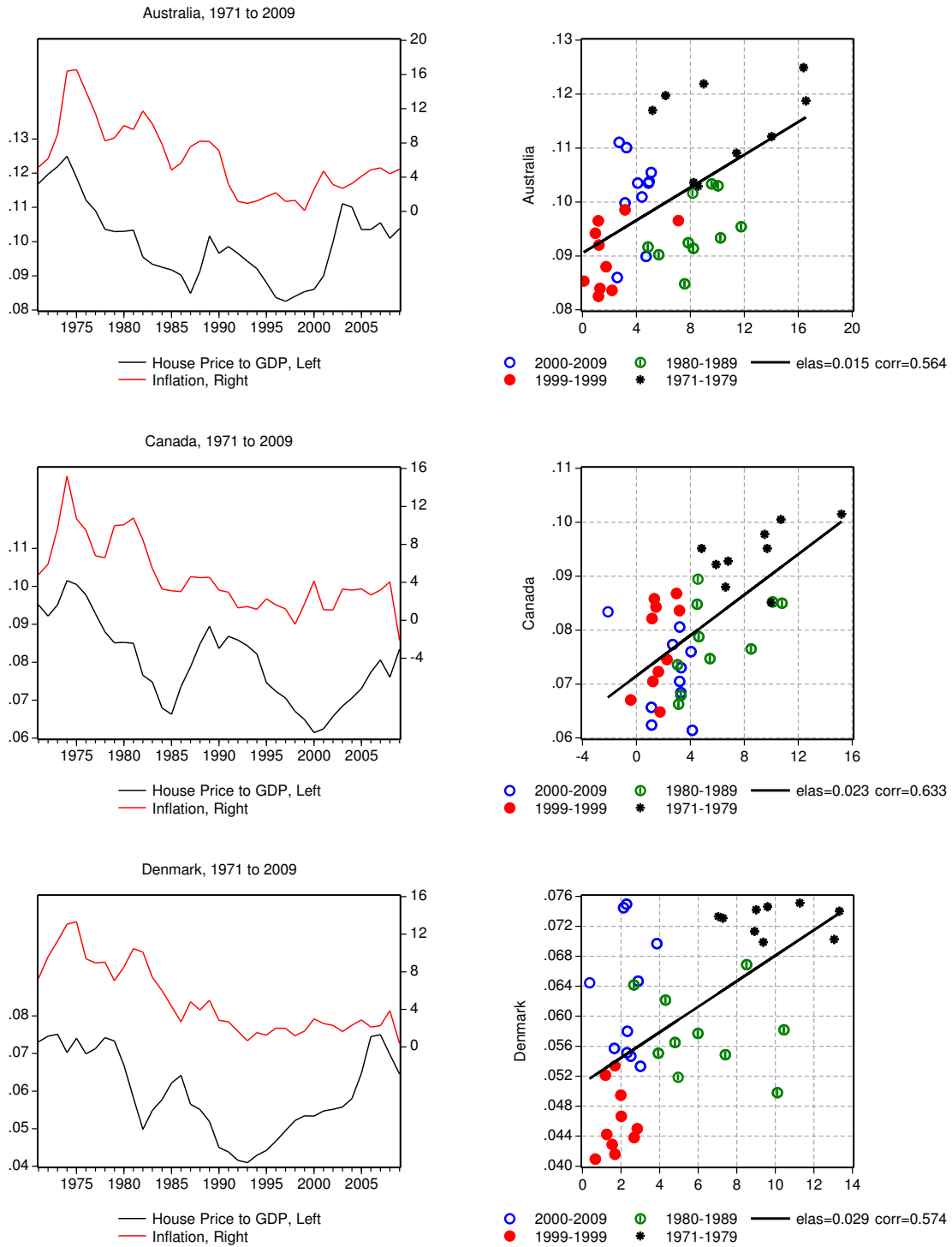


Figure 12

Ratio of HPI to GDP: Finland, Italy, Japan

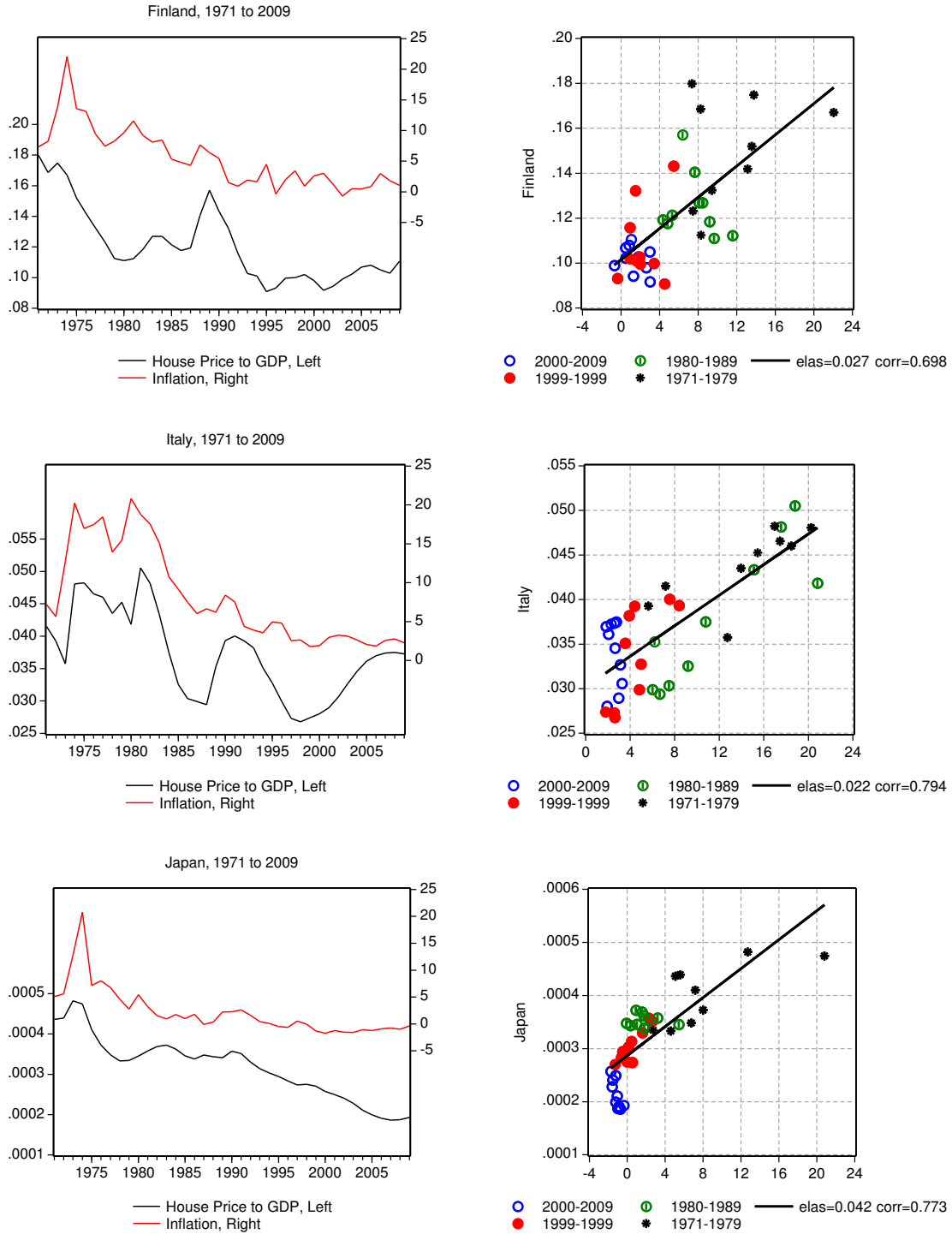




Figure 13

Ratio of HPI to GDP: Netherlands, New Zealand, Norway

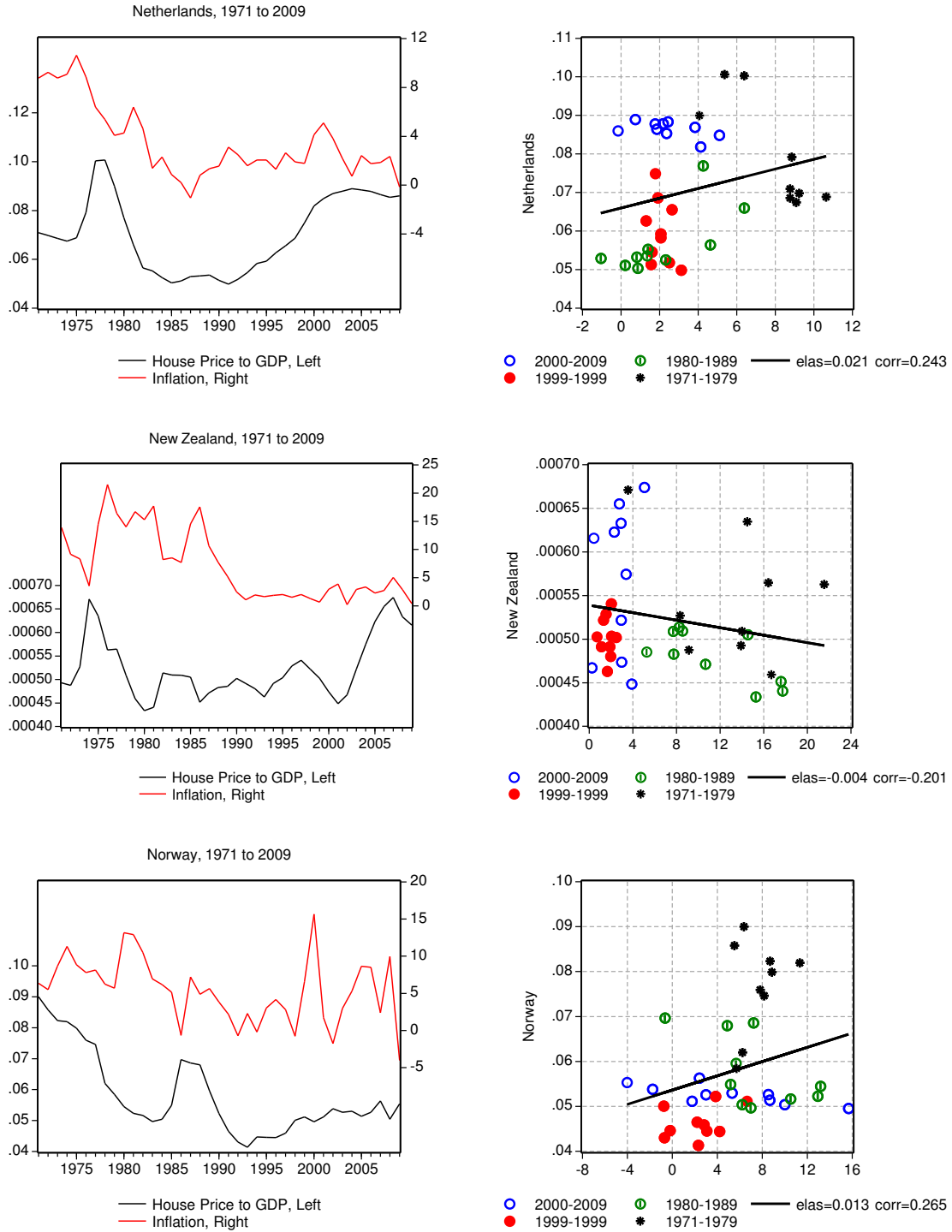


Figure 14

Ratio of HPI to GDP: Spain and Sweden

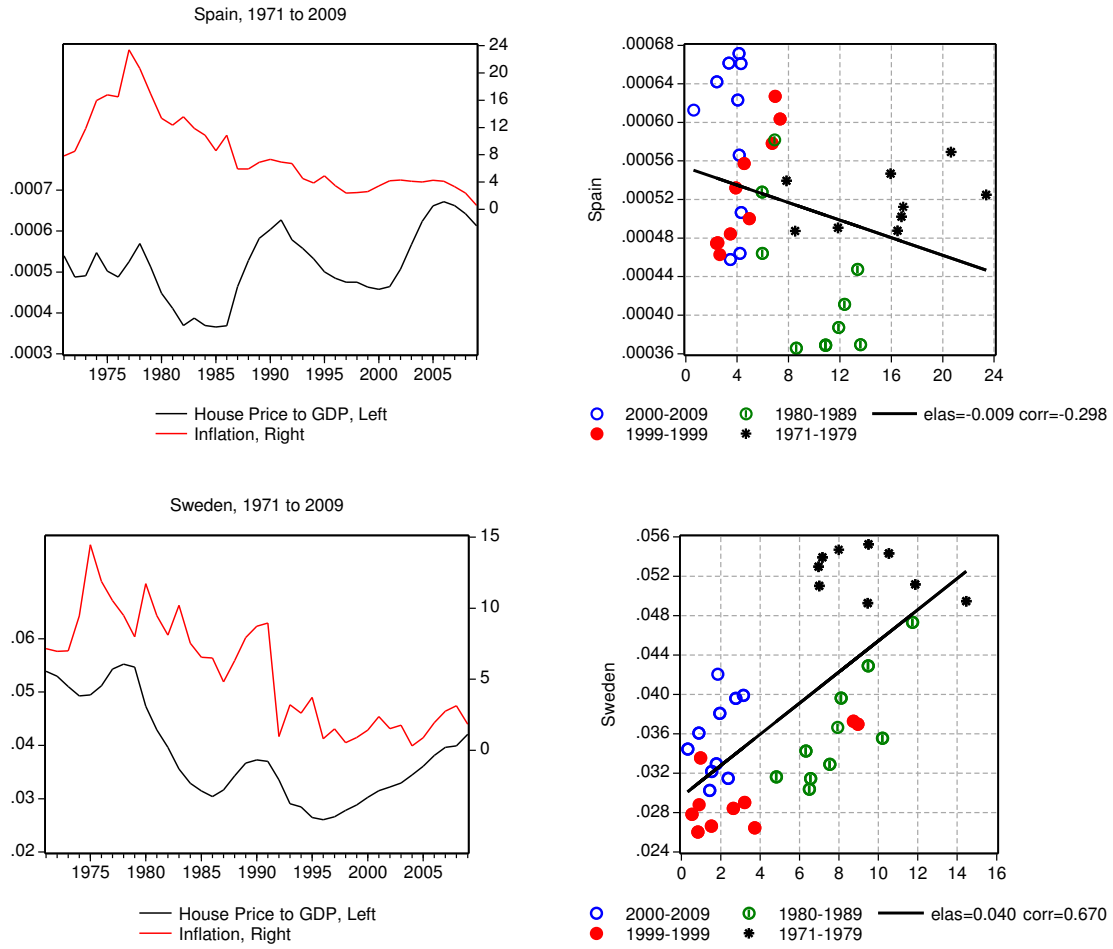
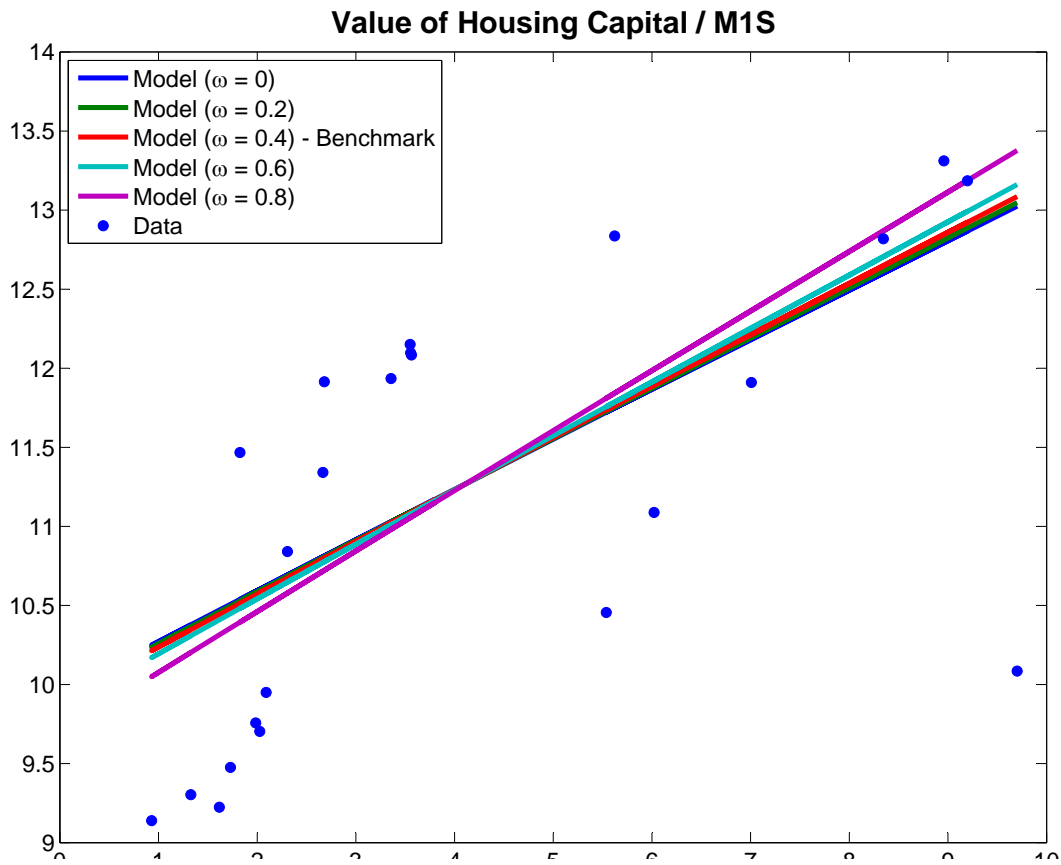


Figure 15: Results from the Model - Benchmark Calibration



Figure 16: Results from the Model - Benchmark Calibration



Appendix: US Data sources

Nominal Stock of Durable Goods	Fixed Asset Tables Table 1.1, line 13 Bureau of Economic Analysis
Davis-Heathcote based Housing Wealth	Davis and Heathcote (2007) available at: <a href="http://www.lincolninst.edu/subcenters/land-values/price-and-quantity.asp">http://www.lincolninst.edu/subcenters/land-values/price-and-quantity.asp</a>
Flow of Funds based Housing Wealth	Flow of Funds Tables Table B.100 line 4 plus Table B.10 line 4 Board of Governors of the Federal Reserve
BEA based Housing Wealth	Fixed Asset Tables Table 1.1 line 2 less Table 1.1 line 7 Bureau of Economic Analysis
DCH based Housing Wealth	Appendix of Davis and Heathcote (2007) Tables 5-12 available at: <a href="http://morris.marginalq.com/landdata_files/2006-11-Davis-Heathcote-Land.appendix.pdf">http://morris.marginalq.com/landdata_files/2006-11-Davis-Heathcote-Land.appendix.pdf</a>
Nominal GDP	National Income and Product Accounts Table 1.1.5 line 1 less Table 2.3.5 line 15 Bureau of Economic Analysis
M1	1959 forward: Cynamon et. al. (2006) "M1S" file available at: <a href="http://www.sweepmeasures.com/data.html">http://www.sweepmeasures.com/data.html</a> Prior to 1959: U.S. Bureau of the Census (1960, Series X-267)
Inflation	National Income and Product Accounts Computed from Price Index corresponding to GDP Based on: Table 1.1.4 line 1 and Table 2.3.4 line 15 Bureau of Economic Analysis
3-Month T-Bill	Monthly data from January 1934 forward available at: <a href="http://www.federalreserve.gov/releases/h15/data.htm">http://www.federalreserve.gov/releases/h15/data.htm</a> Board of Governors of the Federal Reserve
AAA rate	Monthly data from January 1919 forward available at: <a href="http://www.federalreserve.gov/releases/h15/data.htm">http://www.federalreserve.gov/releases/h15/data.htm</a> Board of Governors of the Federal Reserve
Shiller HPI	Shiller (2005) available at: <a href="http://www.econ.yale.edu/~shiller/data.htm">http://www.econ.yale.edu/~shiller/data.htm</a>

Appendix: International Data sources (House Prices)

Belgium	Stadim price index of houses, average price From stadim.be, available at: <a href="http://www.stadim.be/uploads/pdf/indexen2011/WOH-E2010.pdf">http://www.stadim.be/uploads/pdf/indexen2011/WOH-E2010.pdf</a> Annual, 1960 -
France	Ministere de l'Ecologie, du Developpement durable, des Transports et du Logement Available at: <a href="http://www.cgedd.developpement-durable.gouv.fr/rubrique.php3?id_rubrique=137">http://www.cgedd.developpement-durable.gouv.fr/rubrique.php3?id_rubrique=137</a> Annual, 1936 -
Ireland	From Environment, Community and Local Government Average house (including apartments) prices, Second-hand houses, Annual, Whole country (1974 - ) and Dublin (1970-1973)
Switzerland	Swiss National Bank Monthly Statistical Bulletin, O4 <sub>3</sub> Real Estate price indices – total Switzerland, Single family homes Annual, 1970 -
United Kingdom	Nationwide UK house prices since 1952 All Houses (UK) Index Quarterly, 1952:Q4 -

- Data for GDP for all countries comes from the IFS.
- Data for inflation (GDP deflator) for all countries except England and France comes from the World Bank World Development Indicators, which can be downloaded from <http://data.worldbank.org/data-catalog/world-development-indicators> . These data begin in 1961, explaining the use of different data for England and France
- The data for inflation in England are derived from the Retail Price Index (RPI) all items, as published by the Office for National Statistics table RP02.
- The data for inflation for France are from the same source as for house prices:  
[http://www.cgedd.developpement-durable.gouv.fr/rubrique.php3?id\\_rubrique=137](http://www.cgedd.developpement-durable.gouv.fr/rubrique.php3?id_rubrique=137)