Housing Boom and Bust:
Structures have a Leveraged Claim on Housing Output*

by Casey B. Mulligan

University of Chicago

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PRELIMINARY AND INCOMPLETE

Abstract

Since housing prices and construction boomed and then crashed 2000-2008, various theories have been offered with impulses ranging from tastes and technology to public policy and exuberance. The possible impacts of these factors are seen in a different light once it is recognized that only a minority of housing output remains as an operating surplus for the structures' owners. It follows that demand impulses are magnified in their effects on housing prices and construction, and that productivity shocks to the mortgage and real estate industries have the potential to both move housing prices and non-residential consumption in the same direction. Time series for vacancy rates and net operating surplus – a variable emphasized by my approach – clearly show that most of the housing boom was related to expectations of the future, rather than demand, supply, or subsidy conditions during the boom. Aggregate consumption patterns and the crowding out of non-residential construction suggest that the prospect of changes in housing sector costs and productivity explain at least part of the boom.

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2008 was a landmark year in financial history. Two major financial institutions – Washington Mutual and Lehman Brothers – failed. Other major institutions such as the insurer AIG and the mortgage institutions Federal National Mortgage Association (Fannie) and the Federal Home Loan Mortgage Corporation (Freddie) survived only because of government interference. By autumn, interbank lending and commercial paper markets could not function normally because some of the participants were thought to have failure risks. Major financial institutions flirted with failure because they were vulnerable to housing prices, and housing prices crashed in 2007.

For good reason, there is concern that these financial events will damage the wider economy. Predicting the extent of wider damage requires an understanding of the causes of the financial turmoil. The purpose of this paper is to articulate a couple of hypotheses as the fundamental origins of the cycle in housing prices and construction – that is, tastes, technologies, market structures, and public policies that may have caused these events – and link their consequences to the fact that much of the economy's housing output cannot be claimed by the owners of residential structures.

Figure 1's left scale shows a monthly measure of the average value of housing properties, known as the "Case-Shiller Home Price Index," divided by the PPI for residential construction and normalized to 100 in the first month shown (January 2000; both series are seasonally adjusted). The right scale shows residential construction spending as a percentage of personal income. The bottom series measures tenant-occupied housing construction and the top series adds owner-occupied construction. The Figure shows that residential construction grew as housing values did through 2005. Sometime between late 2005 and early 2006, both values and construction spending peaked and have declined ever since. The Figure also shows that the large majority of the amount and changes in residential construction spending are for owner-occupied structures.

Figure 2 displays quantity indices (2000 = 100) for investment in structures of three types: owner-occupied residential, tenant-occupied residential, and non-residential. Unlike the expenditure series used in Figure 1, the series in Figure 1 measure the real quantity of investment. The three types of structures investment stayed in about the same proportions 1993-2000. Both types of residential investment increased significantly 2001-2005, and thereafter fell back to pre-boom amounts. In contrast, investment in non-residential structures fell after 2000, and increased significantly 2005-2007. Because the boom increased both types of residential investment and reduced non-residential structures investment, the question addressed in this paper is why housing prices and construction increased 2000-2005, without particular attention to the distinction between owner-occupied and tenant-occupied housing.

Section I discusses the magnitude of the price boom and bust to be explained, noting that the range of estimates is wide. Section II explains how much of housing output goes for banking services, real estate brokerage, and management. Structures have a leveraged claim on housing output because they are less elastically supplied than are the housing sector's other inputs. Moreover, this raises the possibility that prospects for technical progress in the provision of the elastically supplied inputs both raised housing prices and housing construction. Section III amends the familiar "q-theory" model of housing investment with an elastically supplied intermediate good sector. I measure time series for the net operating surplus and vacancy rates emphasized by the theory, and show how they suggest that optimism about the future fueled the housing boom, rather than tastes, technologies, or subsidies during the boom. Section IV therefore looks at the market dynamics that would be an efficient response to good news about the future. Section V relates the model to claims that low mortgage rates and lax mortgage regulation made the housing cycle possible. Section VI considers the theoretical and empirical relationship between housing construction and non-residential consumption.

I. The Price of Housing: Separating Quantities from Property Values

A variety of measures show real housing prices much higher at their peak in 2006 than they were in 2000 or during much of the 1990s, although the various measures do not agree on the magnitude of the price boom. Figure 3 displays three housing price measures at a quarterly frequency, 2000-2008, each relative to the same PPI for residential construction. The Case-Shiller index (also used in Figure 1) shows 90 percent growth in housing prices relative to PPI over that period. The OFHEO index shows prices grew 30 percent more 2000-2006 than the PPI for housing construction.[2] Both of these indices are based on comparisons of multiple sales of the same property at different points in time. The BEA residential structures price index – designed to reconcile construction expenditures with the characteristics of the stock of housing created by the construction – shows less than 20 percent appreciation.

Himmelberg et al (2005, p. 69) point out that same property comparisons may exaggerate housing price appreciation because properties are improved over time. Indeed, many of the same forces that motivate the construction of new homes would motivate improvements of existing ones. From this point of view, the BEA residential structures price index is the most preferred. One the other hand, it is hard to believe that housing prices appreciated less than 20 percent and that the same-property comparisons would exaggerate price appreciation by a factor of two or more. Clearly, more work is needed to determine the degree to which the various housing price indices also capture changes in the real quantity of housing. For now, I assume that the task for economic theory is to explain housing price appreciation on the order of thirty percent or more.

II. Resource Use in the Housing Industry

II.A. National Accounting for Housing Output

A physical housing structure has value because it helps provide people with flows of shelter, privacy, and convenience. However, landlords and homeowners know that

[2] The OFHEO index is considered by Glaeser, Gyourko, and Saiz, (2008). Mulligan and Threinen (2008) compare growth rates for the OFHEO and Case-Shiller indices 2000-2006. Case-Shiller and OFHEO indices differ, among other things, in terms of houses sampled (OFHEO does not sample foreclosure sales) and value-weighting (Case-Shiller value weights).

housing services flows are not produced with structures alone: also important are intermediate inputs of brokerage, management and banking services that can match and maintain the physical structures with the families who live in them and the investors who build them. As shown in the national accounts, banking, real estate brokerages, and others outside the construction industry annually supply hundreds of billions of dollars worth of the intermediate inputs to the housing industry.

Figure 4 shows the claims on housing output net of depreciation for 2006, as reported by Mayerhauser and Reinsdorf (2007).[3] Almost a third of housing output goes to intermediate goods and services. Another six percent goes to labor (largely management).[4] Thus, the entire rent paid by occupants does not go to the investor in the structure – much of it goes to the suppliers of other resources.

II.B. Prospects for Technical Progress

Some optimism about the future costs of intermediate inputs was warranted because applied information technology was rapidly advancing during the 2000s. Much of the banking, real estate, and property management value added relates to information. Bankers screen borrowers and value heterogeneous collateral. Hall and Woodward (2008) claim "Recent years have seen great improvements in data, especially the introduction of credit scores, which gave lenders new powers to forecast mortgage defaults and to adjust interest rates offered to prospective borrowers. In 1990, credit scores were rare; by 1996, they were standard." Perhaps lenders also expected to use information technology to better monitor and collect on loans, and therefore put subprime lending programs in place.[5]

Real estate brokers match heterogeneous families to heterogeneous properties; among other things, they help reduce vacancy rates. Real estate brokers might also expect to benefit from technical progress: Virtual Office Web sites and their

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[3] Figure 4 shows data for the tenant-occupied housing units only, because the labor of owner-occupants is not included in the national accounts. The results are similar for owner-occupied housing units, except that labor would be zero and the other items proportionally larger.

[4] Henceforth, I do not conceptually distinguish intermediate inputs from compensation of employees.

[5] Himmelberg et al (2005, p. 88) note the emerge of cost-reducing innovations in the mortgage market, although they do not consider that housing boom prices might have embedded some optimism about further progress in this direction.

technological descendants might significantly reduce the brokerage resources needed to match homes with the persons who value them most.

Residential real estate, mortgage, and lease transactions are small as compared to those in the business sector, so the former ought to be a lot more sensitive to transactions and administrative costs. Thus, both real progress and the prospect of additional progress should motivate the most construction in the residential sector (especially units that, absent technical progress, would be intensive in the costs of brokerage, management, etc.), and may even crowd out non-residential construction.

II.C. A Model of the Production and Distribution of Housing Output

Although intermediate inputs appear to be necessary, presumably they are poor substitutes for the structures themselves: one cannot significantly increase the effective square footage of his house by asking his banker or broker to work harder. I therefore model the production of housing services $s(t)$ during period t as a Leontief function of the net stock $h(t)$ of housing structures and the amount $x(t)$ of intermediate inputs supplied:

$$s(t) = \min\left\{h(t), x(t)\right\} \tag{1}$$

I let p_x denote the purchase price of the intermediate inputs and ρ denote the rental rate of housing structures. Perfect competition in the market for housing services will mean that the rental rate r for housing services will equal the total cost of producing each unit:

$$r(t) = \rho(t) + p_x(t) \tag{2}$$

Because $\rho(t)$ is the difference between the rental rate for housing services and the rental rate for (non-structure) resources needed to provide those resources, $\rho(t)$ corresponds to the housing sector's operating surplus (gross of depreciation). Figure 4 shows that, after subtracting depreciation, $\rho(t)$ is less than half of the total rent paid for housing services, so the often-cited result that "housing prices are the present value of housing rents" will prove to be a poor approximation in my model.

Moreover, equation (2) says that even 100 percent equity owners of housing structures have a leveraged claim on housing output: an increase in r holding p_x constant increases the ratio ρ/r. For example, the net operating surplus share shown in Figure 4 implies that a 10 percent increase in the housing rental rate r would increase net operating surplus by more than 20 percent. This leverage is not an artifact of financial arrangements – it does not exist because there may be multiple claims on the income paid to structures. Structures have a leveraged claim on housing output because they are less elastically supplied than are the housing sector's other inputs.[6]

The housing output in Figure 4 pertains to occupied structures; vacant housing produces no output. Conceptually, I treat this additional cost – a structure owner's risk of having no occupant to pay rent – as a cost like the intermediate inputs. With this convention, $r(t)$ must be interpreted as the period t rent earned on occupied housing and $p_x(t)$ as the cost of the intermediate inputs as well as the foregone rent on vacant housing.[7] The vacancy cost could be added to the intermediate goods slice of Figure 4, thereby decreasing the fraction of gross housing rent that goes to structure's owners net operating surplus.[8]

Thus, my model of housing prices and construction explicitly acknowledges the importance of intermediate inputs, and considers how: (a) the existence of intermediate inputs affects comparative statics with respect to other parameters and (b) anticipation of progress in the intermediate goods sector could elevate housing prices.

[6] Many of the formal housing price and construction models do not recognize claims on housing output aside from structures' rent and (occasionally) property taxes. See, for example, Poterba (1984), Topel and Rosen (1988), Himmelberg et al (2005), and Glaeser et al. (2008).
[7] Alternatively, the foregone rent could be moved to the left hand side of equation (2), which would then say that the average gross rent earned (including the zero rent earned by vacant units) equals the surplus rate for the structure owner plus the price of the intermediates x.
[8] However, an offsetting adjustment would be to add to the net operating surplus slice of the Figure, due to the fact that 2006 (the year for which Mayerhauser and Reinsdorf (2007) gave a detailed breakdown of the claims on housing output) had a relatively low operating surplus.

III. Analytical Framework and the Role of Anticipation

I assume that there exists a representative consumer,[9] with preferences over continuous time paths for housing services *s*(*t*) and other consumption items *c*(*t*). Given the near constancy of the housing service share of personal consumption expenditures, it is both realistic and convenient to consider a logarithmic utility function:

$$U = \int_0^\infty e^{-\theta t}\left[\ln c(t) + \eta(t)\ln s(t)\right]dt \tag{3}$$

where θ is a constant preference parameter and η(*t*) is a sequence of preference parameters reflecting the state of aggregate housing demand.[10]

In order to abstract from the details of wage setting and labor supply, I assume that the economy is endowed with a given stream *w*(*t*) of labor product. The labor product together with the production made possible by nonresidential capital *k*(*t*) is available for four types of spending: housing structure investment, housing intermediates, non-residential investment, and other consumption items.

$$\begin{gathered} w(t) + Ak(t) = h(t)S(t)\,f\left(I(t)/h(t)\right) + B(t)x(t) + \dot{k}(t) + c(t) \\ \dot{h}(t) = I(t) - \delta h(t) \end{gathered} \tag{4}$$

where *A* is the (constant) marginal product of non-residential capital net of depreciation and *B*(*t*) is the time *t* marginal rate of transformation between housing intermediates and consumption goods. Dots denote derivatives with respect to time.

I(*t*) is gross residential investment. *Shf* is the cost of that investment, inclusive of installation or "adjustment" costs, with *f′*, *f″* > 0. *Shf* is homogenous of degree one in *h* and *I*, which implies that housing investment is infinitely elastically supplied in the long

[9] This assumption facilitates discussion of efficiency and aggregate wealth effects, but is unnecessary for the other results.
[10] A straightforward embellishment of the model would have multiple housing stocks that differ by location. If preferences were shifting from one region to another, then such a model would imply that the growing regions (in terms of housing preference) have fundamental prices that are above the national average.

run.[11] The convexity of f reflects the imperfect short run supply of resources to construction activities.

S is an exogenous shifter of the cost or productivity of investment activity. In principle, Sf' would be reflected in the measured price of housing investment relative to the price of consumption goods. In practice, changes in relative shadow prices of investment may not be fully reflected in price measures because the latter do not adequately account for waiting times and other convex costs of adjusting capital stocks. I assume that adjustment costs in excess of those reflected in measured investment prices are recorded in the national accounts as spending on housing intermediate goods.

Integration of the non-residential capital accumulation equation helps describe the intertemporal production set for this economy:

$$\int_0^\infty e^{-At}\left[c(t)+B(t)x(t)+h(t)S(t)f\left(I(t)/h(t)\right)\right]dt \le k_0+\int_0^\infty e^{-At}w(t)dt \qquad (5)$$

In words, the present value (using the net marginal product of non-residential capital to discount) of spending on consumption, housing intermediates, and housing investment costs must equal the initial value of non-residential capital plus the present value labor of income. Henceforth, I assume that the rate of time preference θ equals the net marginal product A of non-residential capital, so that the efficient consumption path is constant over time.

I characterize fundamental determinants of housing prices in two steps. First, I calculate the allocation of housing and other goods over time, alternatively assuming either that (a) the allocation is efficient or (b) that the only distortion in the system appears through the intermediaries' price (more on this below). Second, I use the marginal conditions from that allocation to calculate the time path of operating surplus

[11] Some previous studies, such as Poterba (1984), Topen and Rosen (1988), and Glaeser at al (2008), assume that investment costs are not homogeneous, so that housing is less-that-perfectly elastically supplied even in the long run. Because quantitative predictions for housing prices depend on the magnitude of the supply response and I want to be conservative as to the amount of price elevation that can derive from fundamentals, I follow Summers (1981) and Hayashi (1982) in assuming homogeneity.

for a hypothetical owner of one unit of housing. After characterizing fundamental housing prices, I relate housing price comparative statics to aggregate wealth effects.

III.A. Housing Prices and Housing Investment

The system of differential equations below helps characterize both the efficient allocation and allocations in which the supply of housing intermediates is distorted (but all other margins are efficient):

$$\begin{aligned}
&\dot{h}(t)/h(t) = \varphi\left(q(t)/S(t)\right) - \delta \\
&\dot{q}(t) = \left[A + \delta - \varphi\left(\tfrac{q(t)}{S(t)}\right)\right]q(t) + B(t)(1-\sigma(t)) + S(t)\,f\left(\varphi\left(\tfrac{q(t)}{S(t)}\right)\right) - \frac{\eta(t)c}{h(t)} \\
&q(t) \equiv \int_t^\infty e^{-(A+\delta)(\tau - t)}\left[\frac{\eta(\tau)c}{h(\tau)} - B(\tau)\left(1-\sigma(\tau)\right) - S(\tau)\,f\left(\tfrac{I(\tau)}{h(\tau)}\right) + \tfrac{I(\tau)}{h(\tau)}S(\tau)\,f'\left(\tfrac{I(\tau)}{h(\tau)}\right)\right]d\tau \\
&f'\left(\varphi(q)\right) \equiv q
\end{aligned} \tag{6}$$

where σ(t) is the date t subsidy rate for housing intermediates (equal to zero for the efficient allocation). φ is "housing investment supply curve": the inverse of the marginal investment cost function f'. For the moment, q is just a co-state variable defined for analytical convenience. Once paths for h and q have been calculated, a path for housing investment is calculated as $I(t) = \varphi(q(t))$.

It is tempting, but incorrect, to interpret A as "the interest rate." A is the annual opportunity cost of residential investment expenditure: the marginal product of non-residential capital net of depreciation.[12] Subsidies, liquidity considerations, and capital market frictions may cause A to differ from, say, mortgage rates. Those considerations are captured by the model's "subsidy" parameter σ(t).[13]

Consider the competitive equilibria that support the allocations described above. That is, the time paths for housing service rents $r(t)$, rental rates of housing structures ρ(t), housing investment prices $p_I(t)$, and housing intermediate prices $p_x(t)$ that would cause consumers of housing to demand the available housing, owners of housing

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[12] Non-residential capital income taxes are not included in my model, but as an investor's opportunity cost A would properly be measured net of taxes.

[13] For more detailed studies of the determinants of σ(t), see Hendershott and Slemrod (1983), Mayer (1993), Himmelberg et al (2005).

structures to allow their structure to be occupied, suppliers of housing intermediates to supply in the amount $x(t) = h(t)$ (and to incur the adjustment costs associated with housing investment), and the suppliers of housing investment to augment the housing stock at the specified rate. In this case, housing services would rent at the rate $r(t)$ that covered the rental rate of the structure $\rho(t)$ and the payment of intermediates $p_x(t)$ (the equation (2) above). The housing service rental rate $r(t)$ would also be equal to consumers' marginal rate of substitution between housing services and other consumption, which, given the Cobb-Douglas utility function, is $\eta(t)c/h(t)$.

$$
\begin{aligned}
&p_x(t) = B(t)(1-\sigma(t)) + \left[f\left(\tfrac{I(t)}{h(t)}\right) - \tfrac{I(t)}{h(t)} f'\left(\tfrac{I(t)}{h(t)}\right)\right] S(t) \\
&r(t) = \frac{\eta(t)c}{h(t)} = \rho(t) + p_x(t) \qquad (7) \\
&p_I(t) = q(t)
\end{aligned}
$$

where the term in square brackets is the effect of the housing *stock* on average adjustment costs.

The competitive equilibrium interpretation of the co-state variable $q(t)$ is as the date t purchase price of a unit of housing, because it is equal to both the price of new housing and the present discounted value of the rental rates received by each unit of existing housing (recognizing that, due to depreciation, a unit housing at time t will be less than a unit of housing after date t).

$$
\begin{aligned}
&q(t) = \int_t^{\infty} e^{-(A+\delta)(\tau-t)} \rho(\tau) d\tau \\
&\rho(\tau) = r(\tau) - p_x(\tau) = \frac{\eta(\tau)c}{h(\tau)} - B(\tau)(1-\sigma) - \left[f\left(\tfrac{I(\tau)}{h(\tau)}\right) - \tfrac{I(\tau)}{h(\tau)} f'\left(\tfrac{I(\tau)}{h(\tau)}\right)\right] S(\tau)
\end{aligned}
\qquad (8)
$$

Thus, housing investment is a monotone function of housing prices, where the shape and position of that function depends on the supply curve for housing investment. This theoretical result is well known (Poterba, 1984; Topel and Rosen, 1988). Interestingly, the supply curve for housing investment was stable enough during the housing boom and bust 2000-2008 to make this monotone relationship obvious in the data, as in Figure 1.

III.B. Current Versus Future Fundamentals

Equation (8) shows that equilibrium housing prices and investment depend on current and expected future tastes, technologies, and subsidy rates. A greater taste for housing (either in the present or in the future), more productive intermediates (either in the present or in the future), or greater subsidies (either in the present or in the future) are associated with higher prices (in the present) for housing structures.

The flow $\rho(t) - \delta$ of net operating surplus per unit stock in the housing sector can be used to gauge the relative importance of current versus future fundamentals for explaining the current housing price. Future fundamentals that raise price affect the current net operating surplus $\rho(t) - \delta$ only through the current stock $h(t)$, and thus would tend to *reduce* $\rho(t)$. High current demand, currently productive intermediate inputs, or a high current subsidy rate each *increase* $\rho(t)$.

Figure 5 displays the housing sector's aggregate annual net operating surplus per dollar of housing stock at the beginning of each year, for the years 1990-2007.[14] Note that the housing stock is measured in real terms – not in terms of replacement cost – so that the low rates during the boom are due a high real quantity of housing, not a high market value of that housing.[15] The second series uses the 1990-2000 linear trend housing stock as the denominator. It also falls as housing boomed, but less than then series using the actual stock: part (but not all) of the reduced net operating surplus rate is due to an increase of the stock above trend.[16]

The low net operating surplus rates since 2002 shown in Figure 5 may be largely explained by a mismatch between housing demand and supply, which itself suggests that expectations about the future fueled the boom. If intermediate inputs were elastically

[14] The year 2005 value is interpolated because its net operating surplus is very low due to Hurricane Katrina.
[15] Net operating surplus is deflated with the deflator for Personal Consumption Expenditures.
[16] Because owner-occupied housing output is imputed from rental rates of tenant-occupied housing, a shift in demand toward owner occupied could reduce rental rates on tenant-occupied housing and thereby give the false impression of reduced rental rates for the housing sector overall. However, we can at least conclude that tenant-occupied demand was low during this period of relatively high construction in the tenant-occupied sector (see Figure 2).

supplied in the short run, unoccupied structures use intermediate inputs too, and net operating surplus were about a third of gross housing output,[17] then a one percent decline in the housing occupancy rate would reduce the net operating surplus rate by three percent. Thus, it takes a three or four percent decline in the occupancy rate to fully explain the low net operating surplus rates since 2002 (which are about 10 percent lower than they were in the 1990s).

Figure 6 displays an index (year 2000 = 1) of the ratio of real housing consumed to the real stock in place at the beginning of the year. Because the BEA calculates real housing consumption according to structures occupied (by either tenants or owners), this ratio changes because the vacancy rate changes. The other two series in Figure 6 are indexes of the occupancy rate (one minus the vacancy rate) from the Census Bureau. The low occupancy rates during the housing boom suggest that a number of homes were built with characteristics (such as location) not particularly desired by the population at the time, but may have been anticipated to serve future demands.[18]

In summary, low occupancy rates and low income flows to structures owners since 2000 suggest that the housing boom was fueled by expectations about the future, and not demand or supply conditions during the boom itself. The anticipation of favorable future fundamentals (to the extent that the future is not so distant than current housing will already be fully depreciated) raises current housing prices and creates housing investment even before those favorable fundamentals are realized. As the stock accumulates leading up to that realization, housing service rents fall and/or property vacancy rates increase.

IV. Market Dynamics in Response to Future Fundamentals

IV.A. Information Flows

Figure 7 shows how I model the information flows that might describe a housing boom and bust. I assume that labor income $w(t)$ is constant over time. I give particular attention to a specific date T (after 2008). Market participants believe that the taste,

[17] Figure 4 shows that net operating surplus is about half of *net* housing output.
[18] The 2000-2007 increase in the real quantity consumed is 78% of the increase in the total real stock available.

technology, and subsidy parameters η(*t*) and *B*(*t*)[1-σ(*t*)] will remained unchanged before *T* and unchanged after *T*. At time *T*, a single binomial draw with success rate π determines whether the preference parameter jumps up Δ_η and the (net of subsidy) technology parameter jumps down Δ_B. Prior to time zero, market participants believe that π was essentially zero, and thought it highly unlikely that they would ever learn otherwise.[19] During the boom, participants began to learn than π might be significantly greater than zero. For simplicity – and to conceptually distinguish housing price jumps from anticipated appreciation – I assume that this information arrived suddenly and unexpectedly at time zero. A bust occurs when the prior beliefs were confirmed to be correct. In this framework, the largest possible boom and bust is created by a time series of beliefs π(*t*) near zero prior to and after the boom and π(*t*) near one during the boom ($t \in [0,b]$, where $b < T$).

It is useful to decompose the components of the housing price formula involving Δ_η and Δ_η from the others.

$$q(t) = \int_t^\infty e^{-(A+\delta)(\tau-t)}\rho_0(\tau)d\tau + \pi(t)\int_T^\infty e^{-(A+\delta)(\tau-t)}\left[\frac{\Delta_\eta c}{h(\tau)} + \Delta_B\right]d\tau$$
$$\rho_0(\tau) \equiv \frac{\eta c}{h(\tau)} - B(1-\sigma) - \left[f\left(\tfrac{I(\tau)}{h(\tau)}\right) - \tfrac{I(\tau)}{h(\tau)} f'\left(\tfrac{I(\tau)}{h(\tau)}\right)\right]S \tag{9}$$

where ρ(τ) – δ is the net operating surplus per unit stock at date τ, assuming that the "old" parameter values still apply.

IV.B. The Case of Inelastic Supply

The less elastic is the supply of housing investment, the more that information about fundamentals affects housing prices rather than housing investment (Glaeser, Gyourko, and Saiz, 2008). As we see from Figure 1, housing investment did change over time – supply was not completely inelastic – so the assumption (for the sake of argument)

[19] This assumption helps abstract from option value considerations in housing construction (Abel et al, 1996) and focus on the possible effects of first moments. By neglecting option value considerations, I exaggerate the short run supply response to news about futures fundamentals, and thereby understate the housing price impact of that news.

that housing supply was expected to be forever fixed can be used to obtain an upper bound on the housing price effect of the information flows. Specifically, the inelastic supply case is described by:

$$f(I/h) = \begin{cases} I/h & \text{if } I/h \leq \delta \\ \infty & \text{if } I/h > \delta \end{cases} \tag{10}$$

As long as investment does not add to the net stock, each dollar of investment is a dollar of foregone consumption (that is, no adjustment cost). Additions to the net stock are very costly.

Assuming that the housing stock began at a value $h(0)$ that was not too high, the stock will optimally remain constant over time. The time t value of the housing stock is:

$$h(t)q(t)/S = \frac{\eta c - B(1-\sigma)h(0)}{A+\delta} + \pi(t)\frac{e^{-(A+\delta)(T-t)}}{A+\delta}\left[\Delta_\eta c + \Delta_B h(0)\right] \tag{11}$$

As seen from the intertemporal production set (5), expectations of the taste and subsidy rate parameters have no effect on consumption because they do not affect the path of the housing stock. The housing price effect of those expectations is therefore:

$$\frac{q(t)\big|_{\pi(t)=1} - q(t)\big|_{\pi(t)=0}}{q(t)\big|_{\pi(t)=0}} = e^{-(A+\delta)(T-t)}\frac{\Delta_\eta c + \Delta_B h(0)}{\eta c - B(1-\sigma)h(0)} \tag{12}$$

where the numerator is the expected change in the net operating surplus at date T, and the denominator is the net operating surplus at date $t < T$. An anticipated change in demand by itself ($\Delta_B = 0$) has a greater than proportional effect on housing prices (unless that change is sufficiently far in the future) because the owners of residential structures have a leveraged claim on the value of housing output ηc.

Suppose that the intermediate inputs (including compensation of employees) were, as of time T, expected to obtain a perpetual subsidy of $\sigma = 0.5$ rather than the current subsidy rate of $\sigma = 0$, but no increment to demand. Using the percentages from

Figure 4 (47% net operating surplus and 30% intermediates), the housing price impact of that expectation is:

$$\frac{q(t)\big|_{\pi(t)=1} - q(t)\big|_{\pi(t)=0}}{q(t)\big|_{\pi(t)=0}} = e^{-(A+\delta)(T-t)} \frac{0.30/2}{0.47} = e^{-(A+\delta)(T-t)} 0.32 \qquad (13)$$

If instead of a subsidy shock, the anticipated shock to intermediates were to double intermediates' productivity, the expression above would understate the price impact, because the productivity would increase the demand for housing (and all other normal goods). For example, a five percent increase in demand would increase housing prices by about an additional ten percentage points, although this amount needs to be discounted by the length of time until the productivity gain is realized.

Without looking at housing prices themselves, it is difficult to quantify the magnitude of anticipated subsidy changes, demand changes, and productivity advances. However, the calculations above show that, absent supply responses, anticipated subsidy and productivity changes could easily elevate housing prices by tens of percentage points. Anticipated demand increases are even more potent at increasing housing prices.

Equation (12) and Figure 12a shows how information about future fundamentals increases housing prices even before those fundamentals are realized (as measured by the net operating surplus per unit housing). Moreover, the positive derivative of that function with respect to *t* shows that information causes prices to appreciate (prior to date *T*) even if no new information arrives in the interim and current fundamentals are unchanged. This is a basic implication of rational expectations: the market anticipates housing price appreciation in order to make structures' owners willing to retain ownership through out the interval (0,*T*), despite the fact that net operating surplus is low during those years as compared to the net operating surplus anticipated after date *T*. Thus, a rational market that anticipates improvements in net operating surplus must have housing prices that are (a) high relative to current net operating surplus and (b) appreciate over time prior to any realized improvement in net operating surplus.

IV.C. Supply Responses: Unanticipated Fundamentals

At the other extreme of fixed supply is the model with no adjustment costs even in the short run. In this case, the housing stock is unchanged until date T, at which time it jumps immediately to its new steady state. Neither net operating surplus nor housing prices are impacted by either the anticipation or realization of changes in fundamentals.

The actual impact on net operating surplus and housing prices depends on where between these two extremes lies the actual path for the housing stock. Equation (9) and Figure 8 shows how supply responses mitigate the housing price impact of future fundamentals: the positive near term (before date T) impact on the housing stock means a negative near term impact on housing service rents and therefore the net operating surplus rate. This tends to lower price impacts relative to both the fixed supply and perfectly elastic supply cases. The impact on the path of the housing stock after date T is positive relative to the fixed supply case and negative relative to the perfectly elastic supply case. This proves that net operating surplus at each date is less than it would be with fixed supply, so that the price impact is less than it would be with fixed supply. The price impact has to be positive (and thereby greater than in the perfectly elastic supply case), though, in order for positive net investment to be optimal.

In order to say more about the price impact, more has to be shown about the optimal path of the housing stock that solves the dynamical system (6). When model parameters are known to be constant over time, optimal housing prices are defined to be those on the one dimensional stable manifold (a.k.a., "stable arm" or "saddle path") of that system. Those allocations below that manifold (in the $[h,q]$ plane) involve zero housing in finite time, which is not efficient because of the Inada condition on the utility function. Those above the stable manifold violate the transversality condition of optimization.[20]

If the new fundamentals are realized immediately ($T = 0$), each of the terms $B(t)$, $\eta(t)$, $\sigma(t)$, and $S(t)$ are constant over time $t \geq 0$ and the logic above applies. The system is stationary with a single steady state:

[20] More below on violation of the transversality condition of optimization. Given my application of the model to the housing boom, for simplicity I do not include an non-negative gross investment condition. If I did, other arguments may be needed to rule out paths that perpetually have zero gross investment.

$$\frac{\eta c}{h_{ss}} = \left[Af'(\delta) + f(\delta) \right] S + B(1-\sigma) \equiv r_{ss}$$
$$q_{ss} = Sf'(\delta)$$

Figure 9 is a phase diagram in the [h,q] plane showing the dynamics of the stationary system for initial values of h and q that do not coincide with (h_{ss},q_{ss}). The optimal path is the stable manifold of this system – the union of the only two time paths (one from the left and the other from the right) that converge to the steady state. If the fundamentals suddenly and permanently changed at time 0 in a way that left $h(0)$ less than the new steady state, the housing price q would jump up to the point on the stable manifold that corresponded to $h(0)$, and then the system would move along that manifold toward the steady state.[21] Thus, quantifying shape of the stable manifold is essential for quantifying price impacts of changes in fundamentals.

The Appendix shows how to globally calculate the stable manifold to any desired degree of precision. A closed form price impact formula is available when the changes in fundamentals are small and the housing stock began in the steady state (with respect to the previous fundamentals),

$$dq = \lambda \left[d \ln \eta - \frac{d[B(1-\sigma)]}{r_{ss}} \right]$$
$$\lambda \equiv \frac{S}{2\varphi'\left(f'(\delta) \right)} \left[\sqrt{A^2 + 4 r_{ss} \varphi'\left(f'(\delta) \right) / S} - A \right] \tag{14}$$

φ' is the inverse of slope of the marginal adjustment cost function; S/φ' is proportional to marginal adjustment costs.

In order to see how price responses in the presence of adjustment costs (quantified by the parameter λ evaluated at some finite φ') compare to price responses with fixed supply, consider how the parameter λ varies with marginal adjustment costs S/φ', holding fixed A, δ, and r_{ss}. This amounts to holding fixed the steady state while changing the slope of the stable manifold in Figure 9. For this purpose, numerical values are assumed for the marginal product of non-residential capital, the depreciation rate, housing

[21] See Summers (1981, Figure 2) or Poterba (1984, Figure I).

expenditure share, and the relative importance of intermediate inputs as shown in Table 1. Figure 10 shows the result: for a wide range of marginal adjustment costs, the comparative statics of housing prices are about half of what they are in the fixed supply case.

[forthcoming: use housing price and investment data to show that the marginal adjustment cost is about 20]

IV.D. Supply Responses: Anticipated Fundamentals

Consider now the case that the date T change in fundamentals is anticipated as of date $0 < T$. Prior to date zero, the system looks like Figure 9, except that the steady state and dynamics are determined by the "old" taste and technology parameters. After date T, the system looks like Figure 9 with the steady state and dynamics are determined by the "new" taste and technology parameters and the economy moving along the stable manifold toward the steady state. Figure 11 illustrates by using red to indicate dynamics according to the old parameters, and black to indicate dynamics according to the new parameters. During the interval $t \in (0,T)$, the dynamics correspond to the "old" parameters, but instead of converging to the steady state along the "old" stable manifold, the economy is following those dynamics that leave it on the "new" stable manifold exactly at date T.[22]

Figures 12a and 12b show the time paths for housing prices and the housing stock. Housing prices jumps up at time zero, increase over time until time T, and then gradually decline back to S after time T. This is the same qualitative price pattern as is the case of fixed supply.

Gross housing investment follows the same qualitative pattern as do housing prices. As shown in Figures 12b, the housing stock therefore accelerates prior to date T and decelerates (but still grows) after date T.

The equilibrium dynamics can be calculated recursively. First, I calculate the stable manifold that describes the dynamics after time T. Then I choose the point on that manifold so that following the old parameter dynamics backwards leaves the housing stock at h_{ss} in exactly T units of time.

[22] See Summers (1981, Figure 5) for a related analysis of an "announcement effect."

[forthcoming: value for *T* and combined parameter shock that cause the date zero housing price to jump 20%]

V. Easy Money, Lax Regulation, and Other Possible Mortgage Distortions

Another hypothesis is that housing was excessively subsidized for a period of time roughly coinciding with the housing boom, and that the housing price reductions occurred as the end of the subsidy came near. Possible forms of the subsidies are homeowner income tax breaks, lax mortgage market regulation, and artificially low mortgage rates. Some versions of the hypotheses are specific to owner-occupied housing, and others apply to tenant-occupied housing or even non-residential capital. The model above implies that housing subsidies raise housing prices, but that does not mean that subsidies were largely or even partly responsible for the housing boom of 2000-2006.

30 year fixed mortgage rates were around six percent per year for most of the boom, and somewhat lower now. Thus, these mortgage rates cannot explain why housing prices 2006 housing prices were so high relative to housing prices in 2003 or 2008. One year mortgage rates were low (as were Fed funds rates) during the housing boom, but I see three reasons why this cannot be a major factor in the housing boom. First, I am not aware of a reason why low short term interest rates would discourage non-residential building at the same time that it caused a boom in housing construction.

Second, if they have any effect (rather than just affecting the division of housing sector operating surplus between mortgage interest and business income), low mortgage rates are properly interpreted as a subsidy to the ownership of assets (such as houses) that can be used as collateral for said mortgages. As shown above, anticipated subsidies seem to be a more important pricing factor during the housing boom than actual subsidies (see also Himmerberg et al, 2005, p. 89).

Third, even if I were wrong to conclude (based on my Figure 5) that housing boom net operating surplus rates were low, the fixed supply case shown above is sufficient to show that the price effect should be small. To see this, suppose that annual real interest rates were going to be one percentage point (100 basis points) lower for a year, and this actually increased the housing sector net operating surplus for that year.

Because houses last for so long, the operating surplus for the year is still a small fraction of the total value of housing.

To the degree that the net operating surplus data are critical to evaluating subsidy hypotheses, it is important to recognize one of the weaknesses of the available measures of that surplus. In particular, owner-occupied housing output is imputed from the occupancy rates of those structures, and from the rents paid by *tenants* in similar structures. To the degree that subsidies received by occupants favor owner-occupied properties over tenant-occupied properties, rents paid by tenants would fall relative to the value of services (inclusive of the subsidy) received by owner-occupants and the value of housing services would be understated due to the imputation.[23] However, subsidies received by structures owners would have the opposite effect. Moreover, none of this explains why the construction of tenant-occupied properties boomed while non-residential construction was down (Figure 2).

VI. Anticipated Technical Change: Evidence from Consumption

Consumption is constant over time unless news arrives about the nature of the intertemporal production set (5), re-arranged below to solve for the optimal amount of consumption.

$$c = Ak_0 + A\int_0^{\infty} e^{-At}\left[w(t) - B(t)h(t) - h(t)S(t)f\left(I(t)/h(t)\right)\right]dt \tag{15}$$

Expectations of the taste and subsidy rate parameters have no effect on consumption except through the path of the housing stock. Thus, if it were learned that future housing demand or housing subsidies would be high, that would immediately reduce non-housing consumption and (as shown in Section V) lead to a path of increasing housing construction. Conversely, news of low housing demand or housing subsidies would immediately increase non-housing consumption and lead to a path of decreasing housing construction.

[23] Due to the subsidy, homeowners may obtain a flow of services from an unoccupied property, even though the national accounts measures that flow as zero.

News about the productivity 1/*B* of the housing sector's intermediate inputs can move non-housing consumption and housing investment in opposite directions. For example, news about that future *B* is smaller is good news about the size of the intertemporal production set and could immediately increase non-housing consumption via a wealth effect. Thereafter, it would increase housing investment as the economy approached the new and higher steady state stock.

Figure 13 shows durable and nondurable consumption spending over time as a ratio to personal income. Consumption of services is deliberately omitted because a large component of that is housing. Consumption rises faster than personal income during the first few years of the boom – arguably the years when market participants became optimistic about technical progress in mortgages, etc. Consumption fell somewhat more than personal income in late 2006, although the biggest drops are in the second half of 2008.

VII. Conclusions

Two empirical findings suggest that optimism about the future (perhaps rational, perhaps not) fueled the housing boom, rather than tastes, technologies, or subsidies during the boom. First, the nationwide net operating surplus per unit of housing was quite low during the housing boom 2002-2006. The low surplus rate is especially evident in the vacancy data. Second, already high housing prices were widely expected to rise further – and did for a couple of years. If 2002-2006 had been characterized by a heavy demand for space, or especially low costs of banking, brokerage, or real estate management, then the net operating surplus should have been high during those years and prices would have been falling as supply increased in response the favorable market conditions. These observations make it hard to conclude that the Federal Reserve's "easy money," or that lax mortgage regulation during the 2000s were major factors driving housing prices.

The housing cycle cannot necessarily be blamed on (supposedly) innate weaknesses of the marketplace, because a well-functioning marketplace that anticipated eventual technical progress in mortgages and real estate brokerage and/or eventually high future housing demand would have produced high and rising prices of housing structures.

The fact that returns to structures themselves are less than half of the cost of providing housing services means that demand changes have a multiplier effect on housing prices. Moreover, optimism about future productivity of the other inputs should also increase housing prices. Finally, the expectation that housing construction costs would someday increase to their high 1990s levels might also cause housing prices to be high and rising during the 2000s. A combination of these factors pushing in the same direction could raise housing prices by tens of percentage points.

Of course, these theoretical results do not prove that the housing market was functioning well. But, as Flood and Hodrick (1990, p. 99) put it, "when agents expect the future to be somewhat different than history" price movements induced by fundamentals may look like bubbles to a researcher who is not fully aware of those fundamentals. Given the real prospects for progress in the housing and related industries, a better quantitative understanding of those prospects is needed.

Non-housing consumption was high during the boom and low afterwards. Unless it is just a coincidence, this suggests that housing demand (current or future, or both) does not explain the housing boom by itself. News about high future housing demand should have no effect on aggregate consumption for a given housing stock, and, because increasing the housing stock takes resources, would ultimately decrease aggregate consumption. Subsidies would have a similar (and thereby counterfactual) impact on aggregate consumption. In contrast, good news about the productivity of the housing sector's intermediate inputs would increase aggregate consumption.[24]

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[24] This conclusion might appear to disagree with Buiter (2008), which argues that changes in housing prices are not wealth effects in the sense that they do not enter the demand for non-housing goods because housing is both an asset and a consumption good. I agree with Buiter that housing prices changes that reflect changes in the current or expected future demand for housing are ultimately redistributive. But housing price changes that reflect changes in the aggregate intertemporal production set – such as the changes in my model's parameter B – are associated with an aggregate wealth effect, even if they are absent from Buiter's (2008) model.

VIII. Appendix: Calculation of the Stable Manifold

The stable manifold is the solution to the dual boundary value dynamical system:

$$\dot{H}(t) = \varphi\left(q(t)/S(t)\right) - \delta$$
$$\dot{q}(t) = \left[A + \delta - \varphi\left(\tfrac{q(t)}{S(t)}\right)\right]q(t) + B(t)(1-\sigma(t)) + S(t)f\left(\varphi\left(\tfrac{q(t)}{S(t)}\right)\right) - \eta(t)ce^{-H(t)}$$

$$\lim_{t\to\infty} q(t) = Sf'(\delta) \quad , \quad \lim_{t\to\infty} H(t) = \ln h_{ss} \quad , \quad H(0) \text{ given}$$

As shown by Mulligan (1991), the stable manifold can be represented as a single function $q(H)$ that solves a single differential equation with a single boundary condition:

$$q'(H) = \frac{\left[A + \delta - \varphi\left(q/S\right)\right]q + B(1-\sigma) + Sf\left(\varphi\left(q/S\right)\right) - \eta ce^{-H}}{\varphi\left(q/S\right) - \delta}$$
$$q_{ss} = q'(\ln h_{ss})$$

$$\lim_{H\to\ln h_{ss}} q'(H) = \frac{S}{2\varphi'\left(f'(\delta)\right)}\left[A - \sqrt{A^2 + 4r_{ss}\varphi'\left(f'(\delta)\right)/S}\right]$$

$$r_{ss} \equiv \eta c / h_{ss}$$

$q(H)$ is readily calculated numerically by integrating $q'(H)$ away from the steady state point.

Table 1. Calibration of Housing Market Parameters

parameter	symbol	value	units (of value)
opportunity cost (marginal non-residential product)	A	5	%/year
housing depreciation rate	δ	3	%/year
intermediate expenditure per unit opportunity cost	$B(1-\sigma)/A$	36/47	share
housing expenditure share	$\eta/(1+\eta)$	15	%

Sources: National Accounts and Annual Population Growth

Fig 1. Housing Construction and Average Property Values

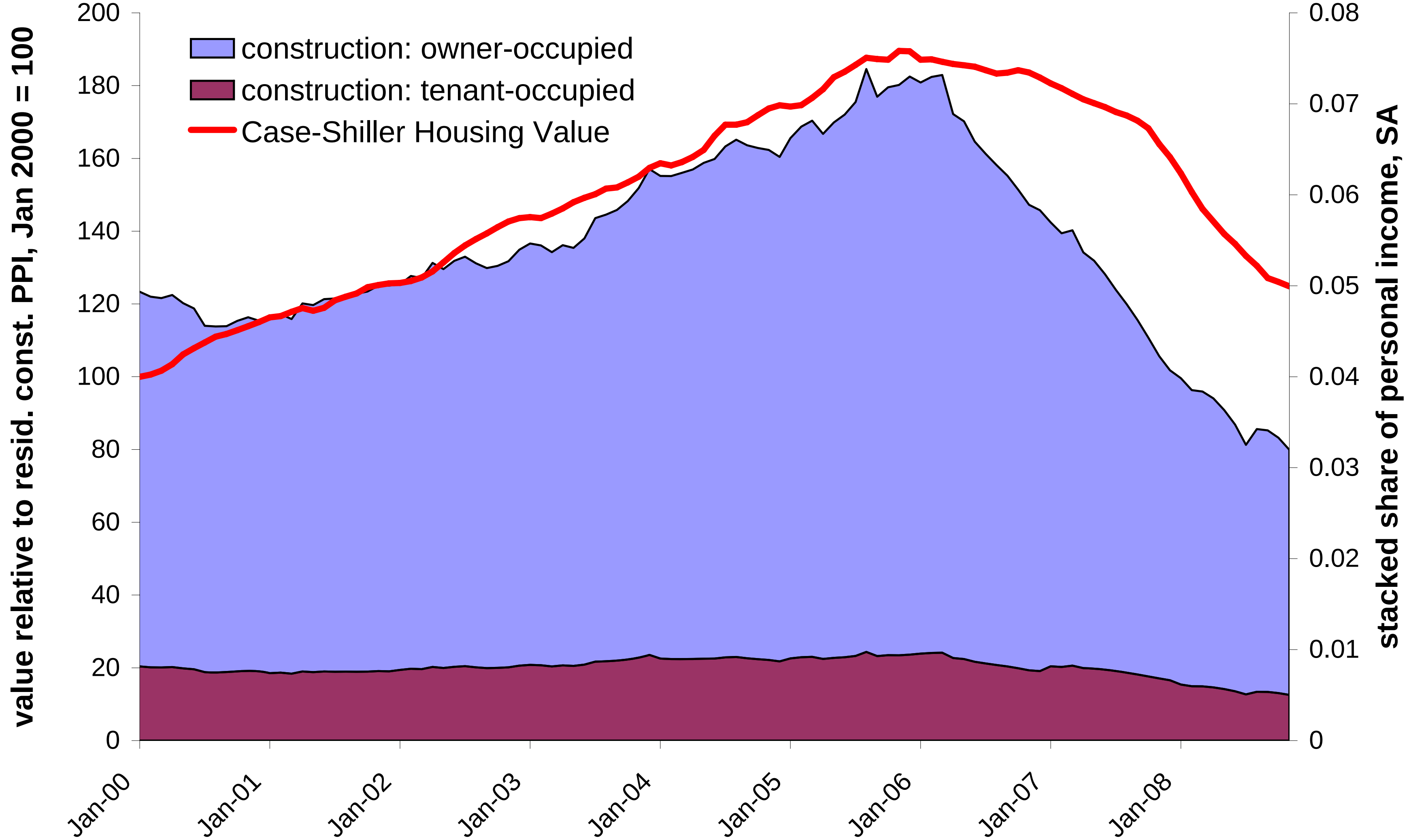


Fig 2. Quantity Indexes for Investment in Structures

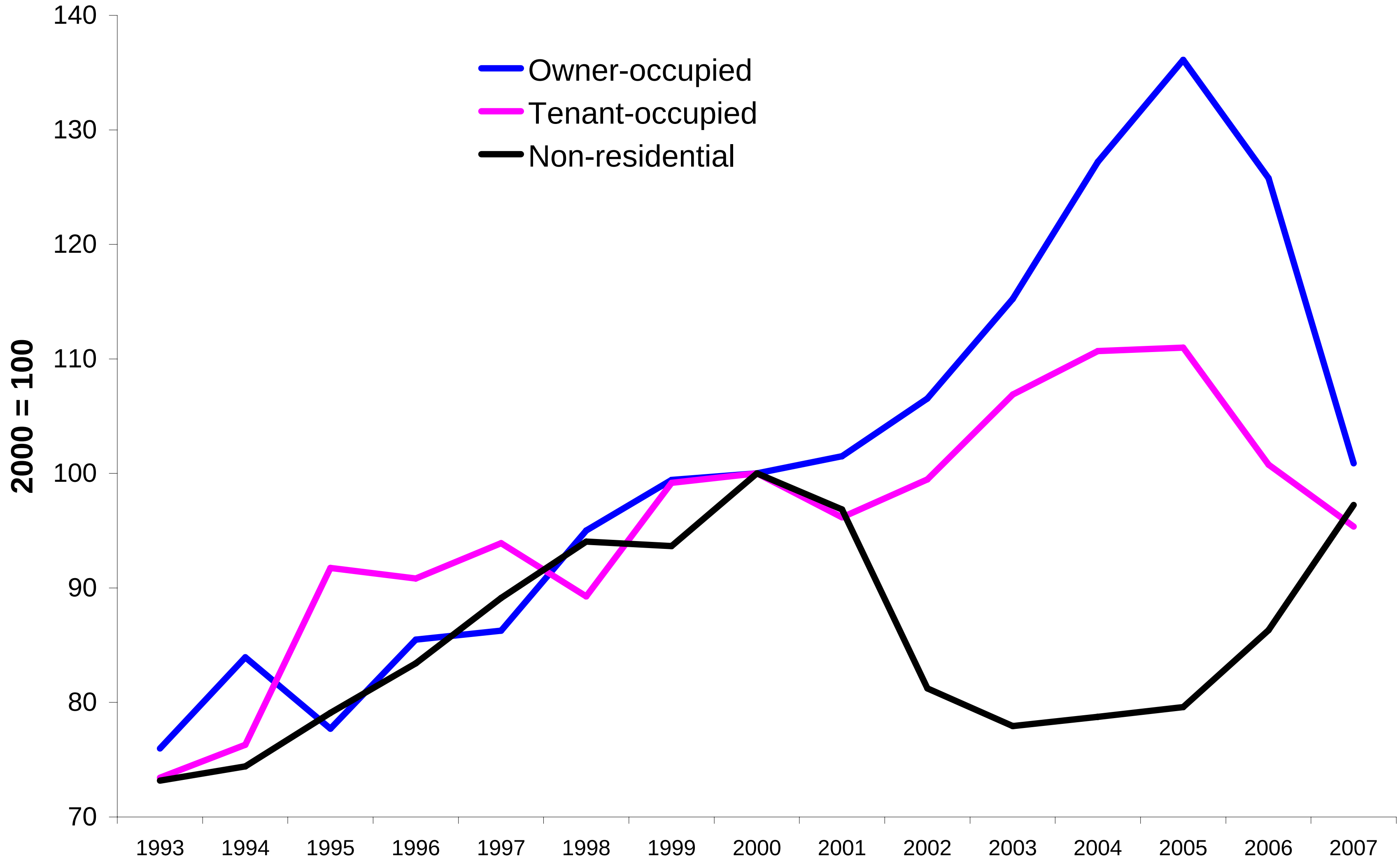


Fig 3. Three Housing Price Indices

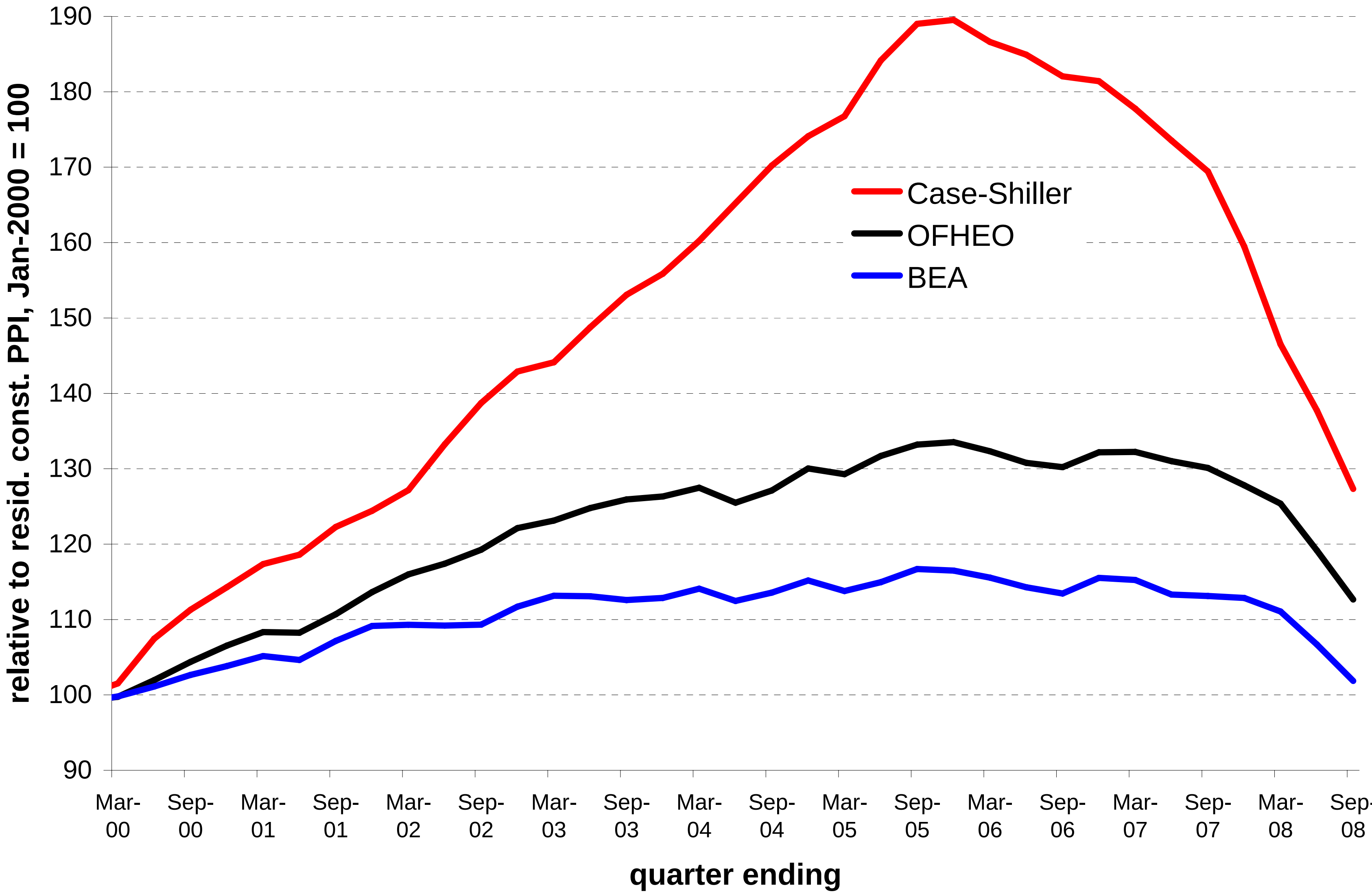


Fig 4. Claims on Net Tenant-Occupied Housing Output, 2006

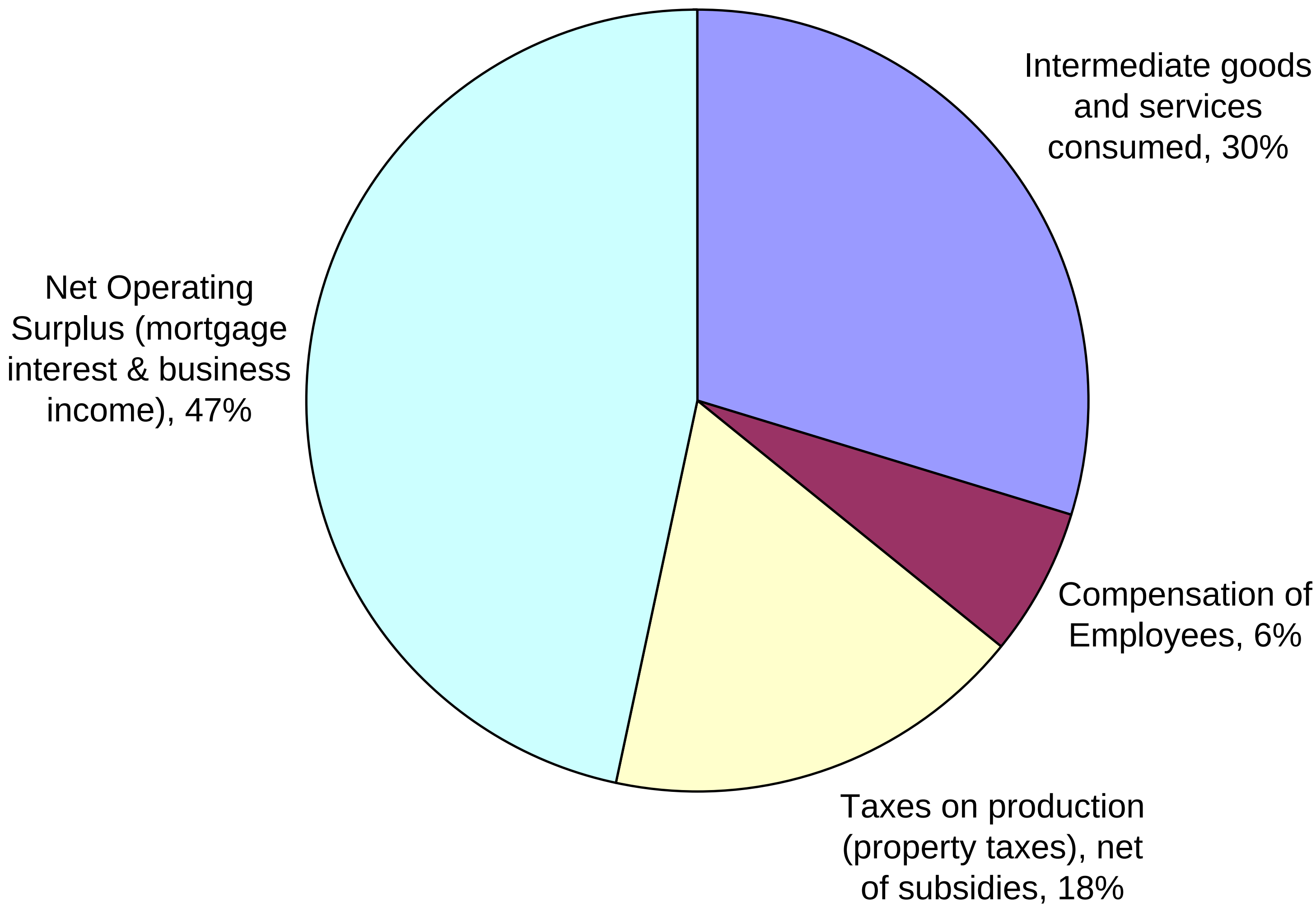


Fig 5. Housing Sector Net Operating Surplus per Unit Real Stock
(2005 interpolated)

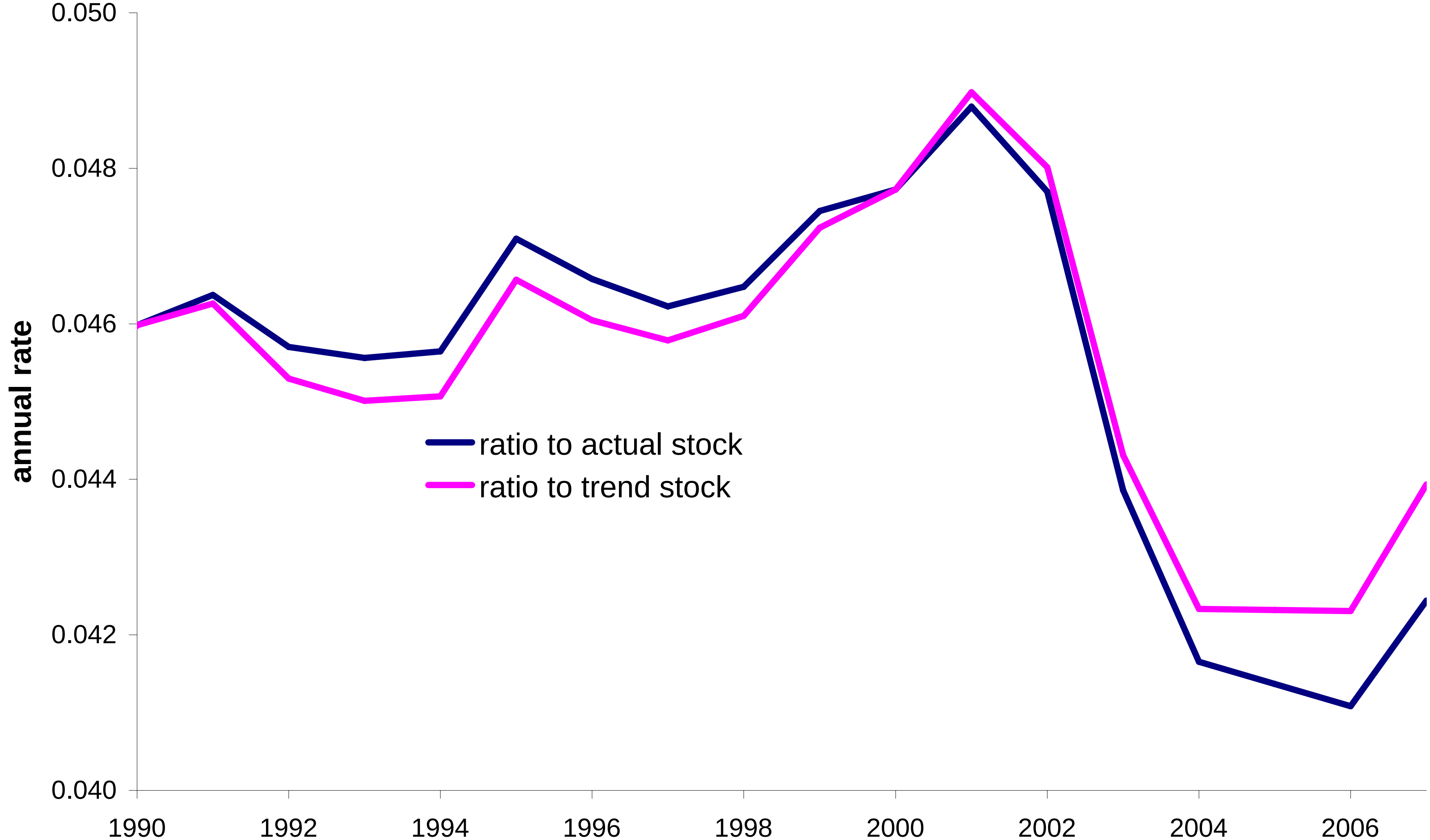


Fig 6. Occupancy Rates, 1985-2007

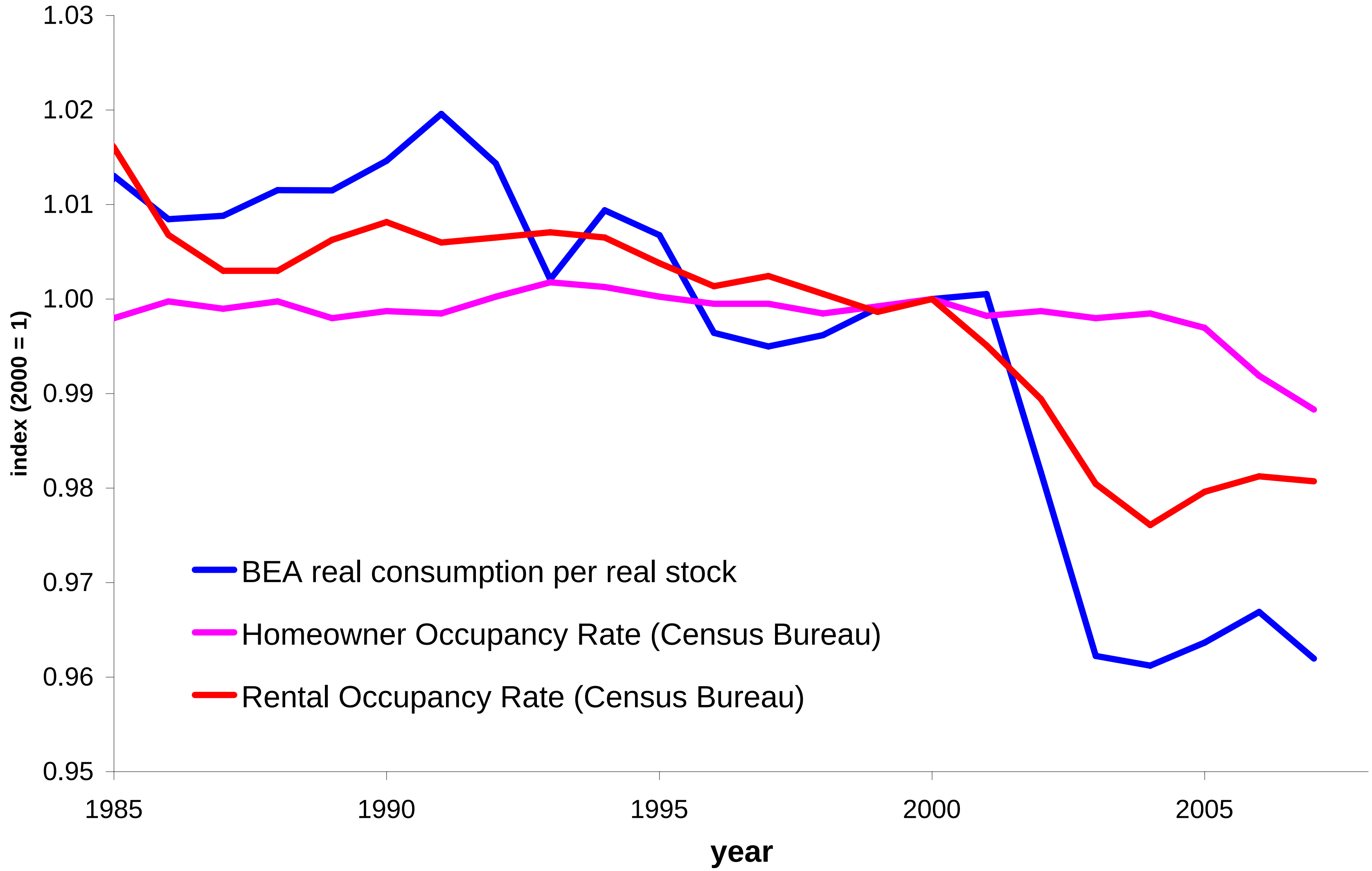


Fig 7. Assumed Information Flows

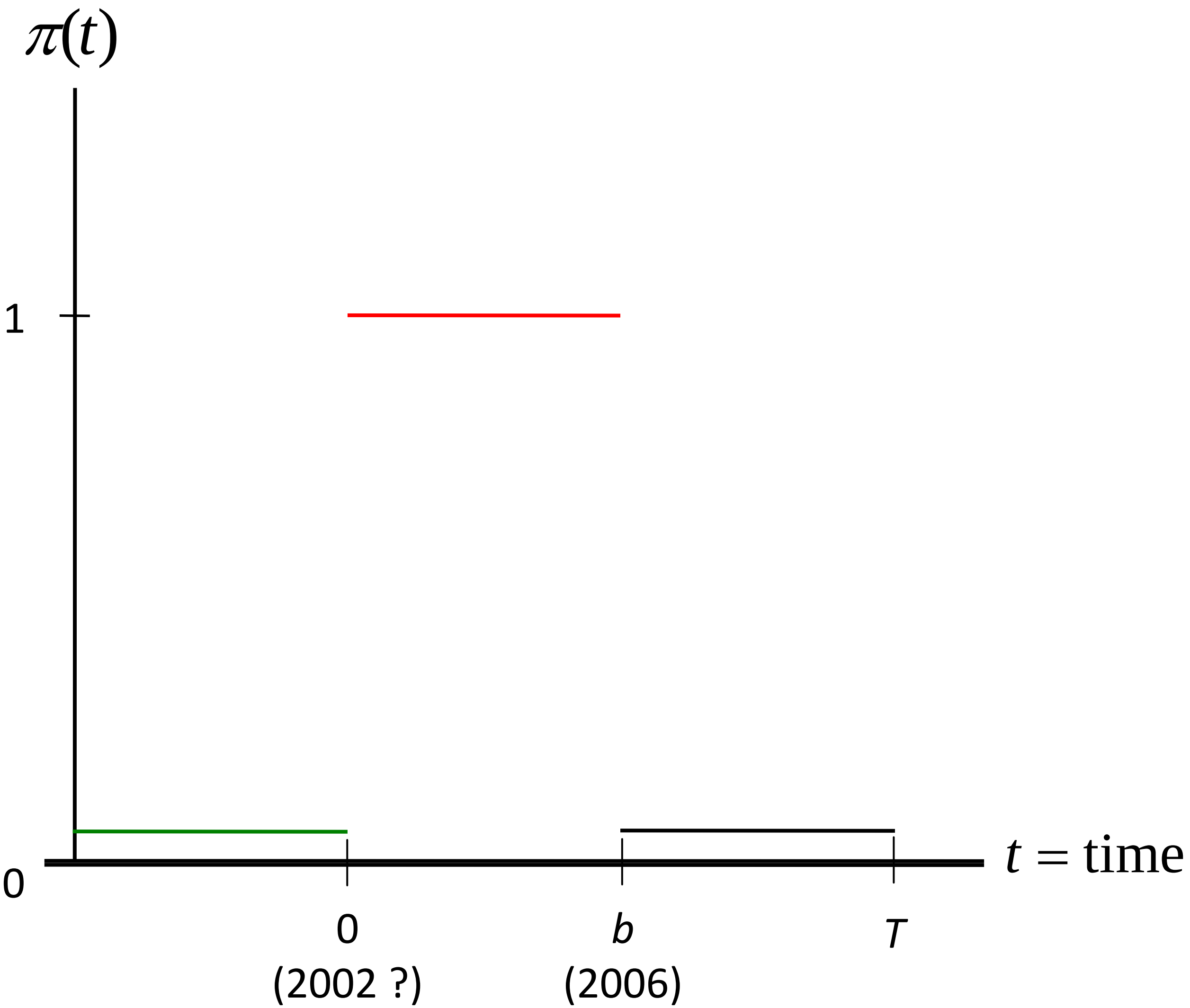


Fig 8. Possible Housing Stock Paths

The Figure shows three housing stock time paths corresponding to three alternative assumptions about the costs of investment.

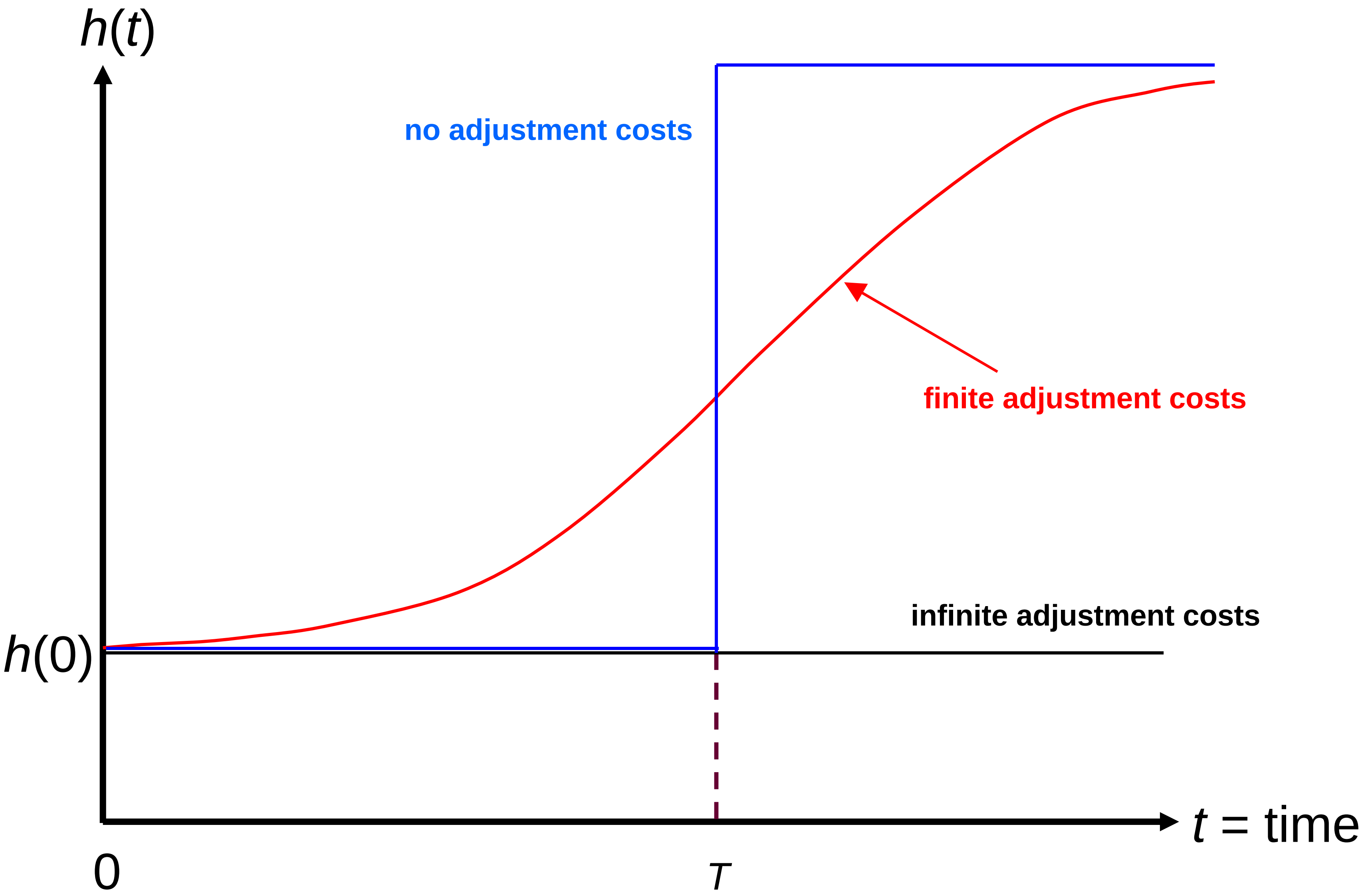


Fig 9. Phase Diagram for the Stationary System

The Figure shows the stationary system's steady state, dynamics, and stable manifold.

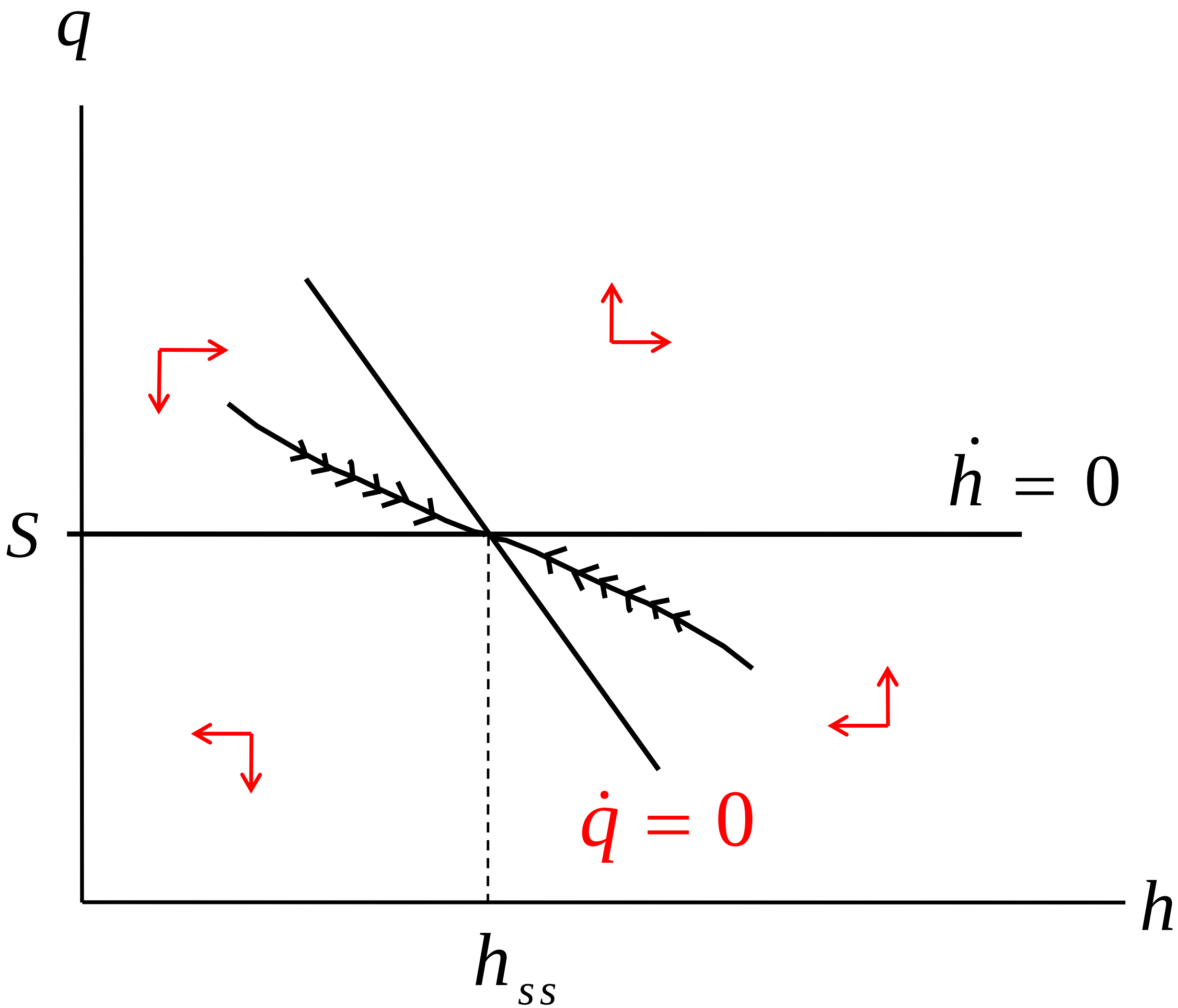


Fig 10. Price Responsiveness Rises with Adjustment Costs

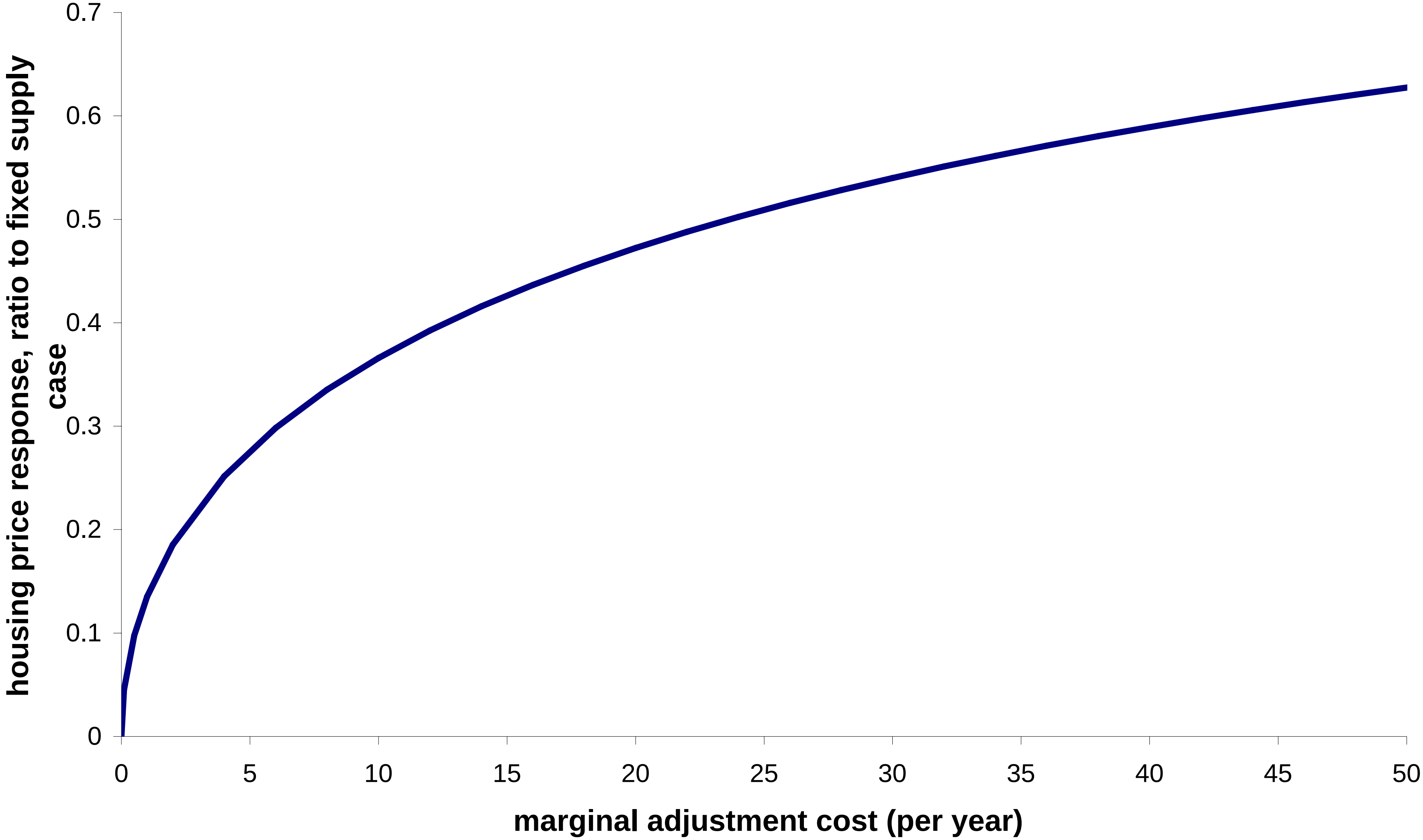


Fig 11. Phase Diagram for Anticipated Changes

The Figure shows the system's dynamics and stable manifold. The dynamics shown by the red arrows correpond to the "old" taste and technology parameters. When the new parameters are first anticipated at date 0, price jumps up. The economy then follows the red path, reaching the end exactly at time *T* when the new parameters take effect. The new stable manifold (shown as a black path) describes dynamics thereafter.

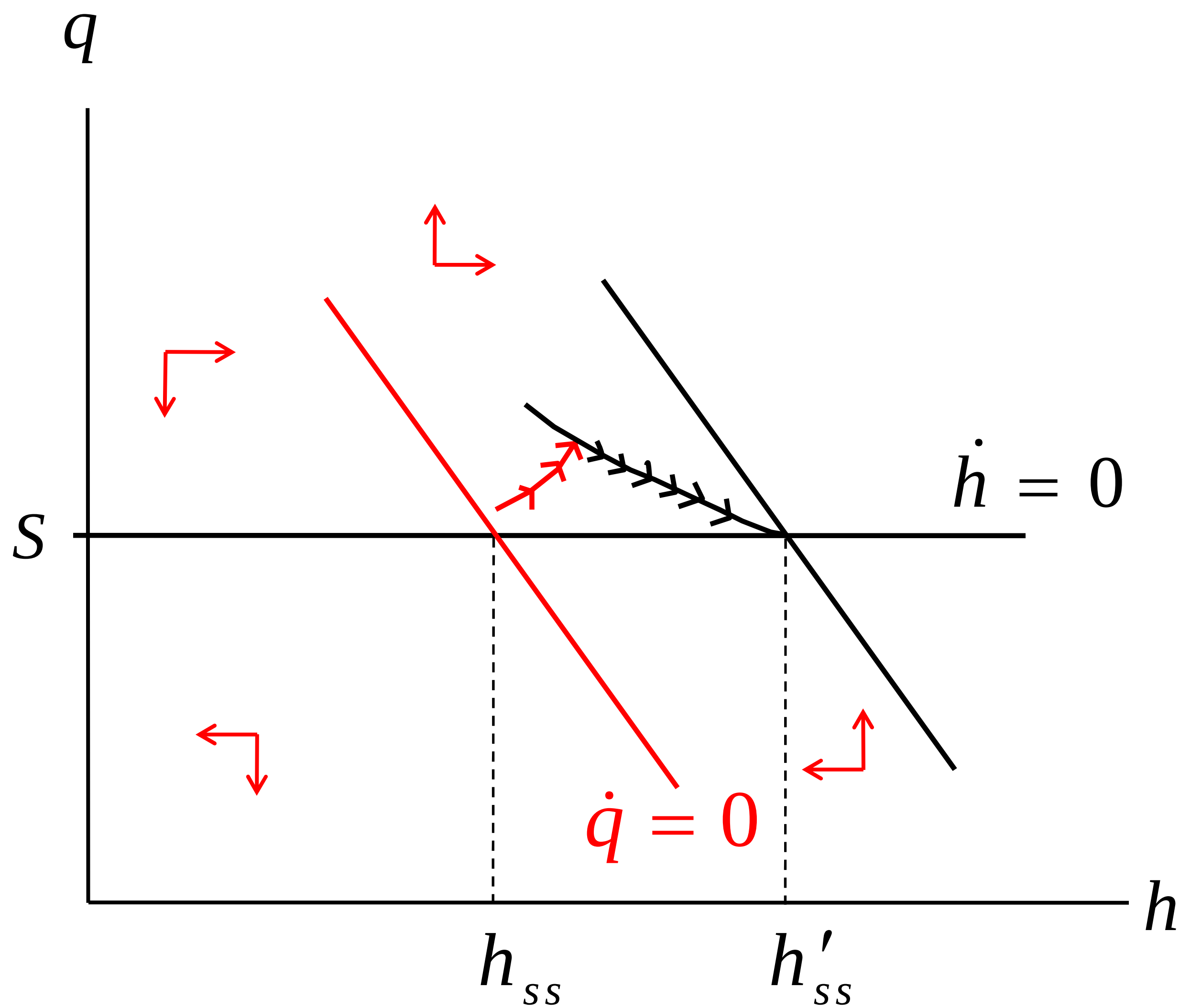


Fig 12a. Time Path for Housing Prices

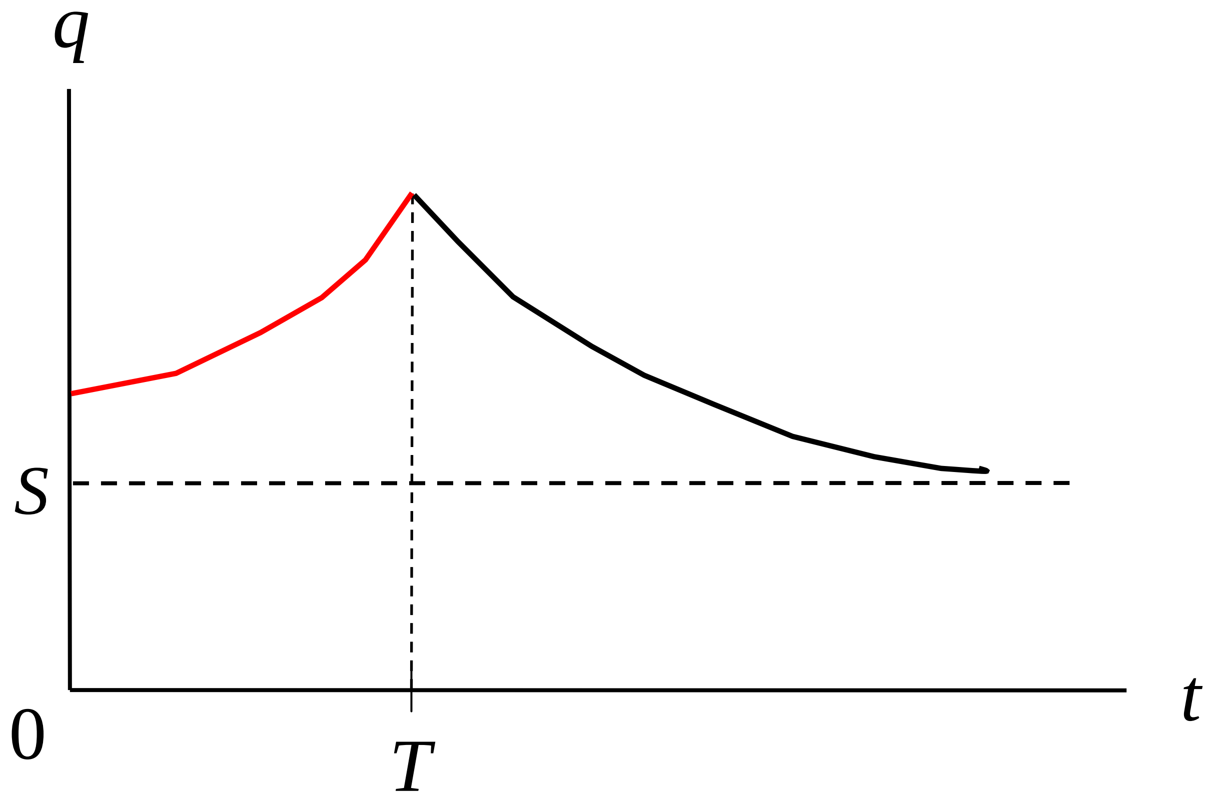


Fig 12b. Time Path for the Housing Stock

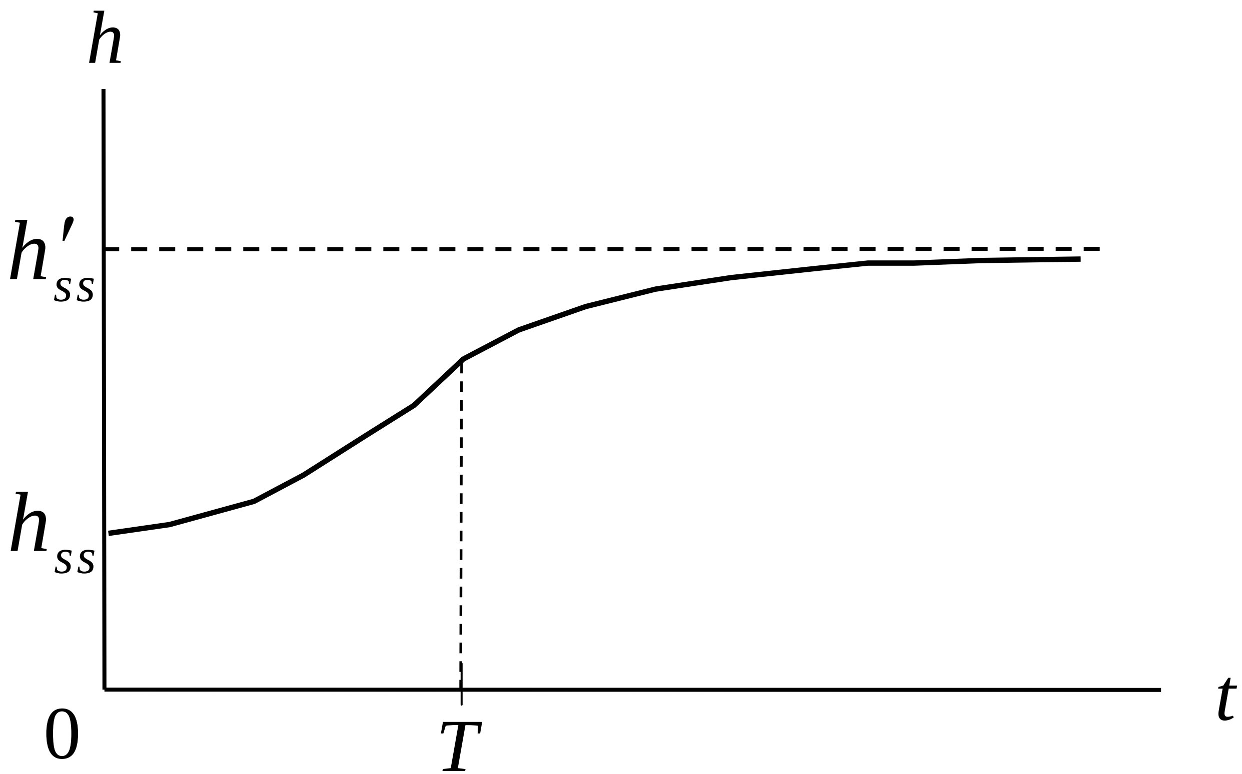
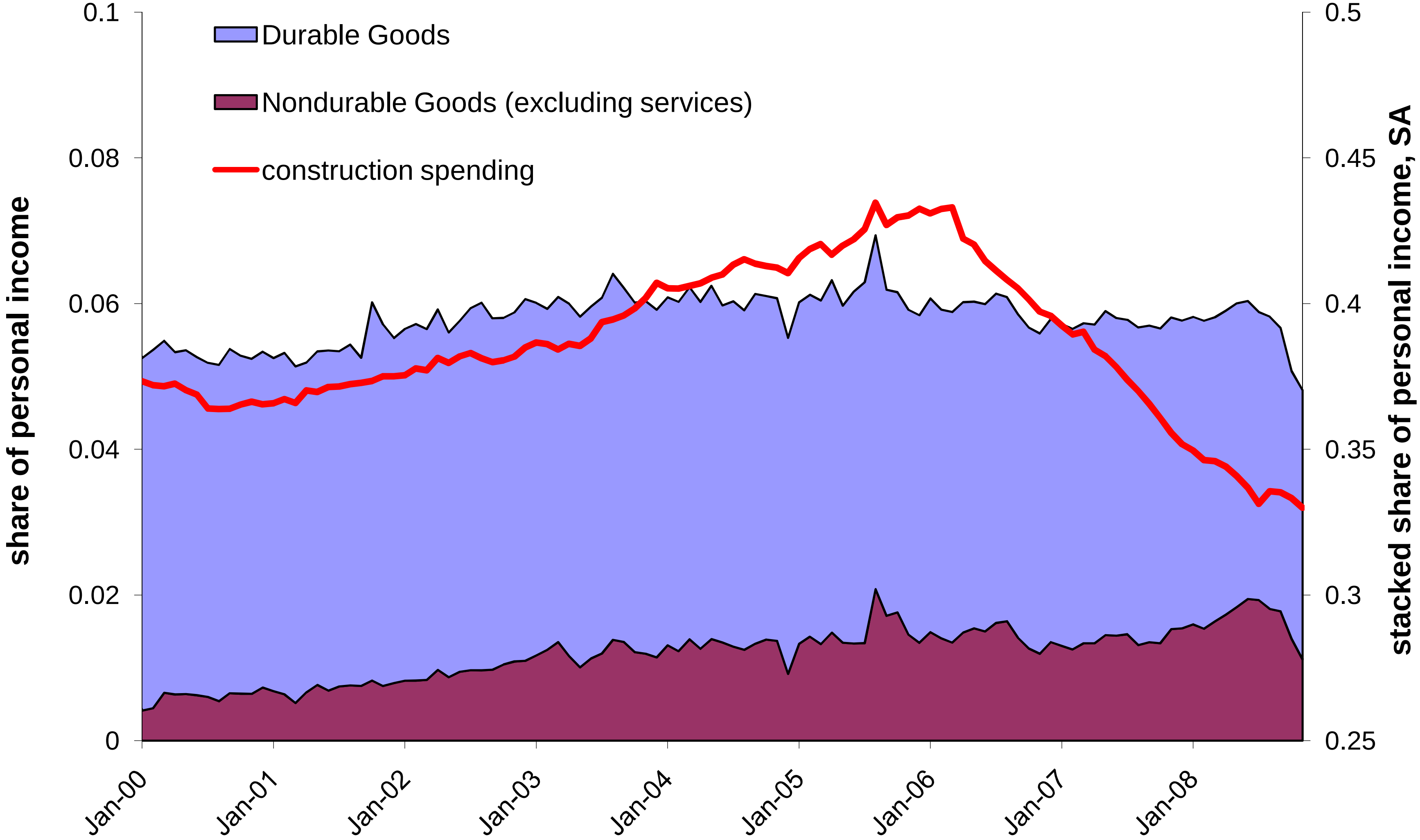


Fig 13. Personal Consumption compared with Construction Spending



IX. References

Abel, Avinash K. Dixit, Janice C. Eberly, Andrew B. and Robert S. Pindyck. "Options, the Value of Capital, and Investment." *Quarterly Journal of Economics*. 11(3), August 1996: 753-777.

Buiter, Willem H. "Housing Wealth Isn't Wealth." NBER working paper no. 14204, July 2008.

Flood, Robert P. and Robert J. Hodrick. "On Testing for Speculative Bubbles." *Journal of Economic Perspectives*. 4(2), December 1990: 85-101.

Glaeser, Edward L., Joseph Gyourko, and Albert Saiz. "Housing Supply and Housing Bubbles." *Journal of Urban Economics*, 2008.

Hall, Robert E. and Susan E. Woodward. "The Financial Crisis and Recession." Manuscript, Stanford University, November 24, 2008. (http://sites.google.com/site/woodwardhall/)

Hayashi, Fumio. "Tobin's Marginal q and Average q: A Neoclassical Interpretation." *Econometrica*. 50(1), January 1982: 213-224.

Hendershott, Patric and Joel Slemrod. "Taxes and the User Cost of Capital for Owner-Occupied Housing." *Journal of the American Real Estate and Urban Economics Association*. 10(3), Winter 1983: 375-93.

Himmelberg, Charles, Christopher Mayer, and Todd Sinai. "Assessing High House Prices: Bubbles, Fundamentals and Misperceptions." *Journal of Economic Perspectives*. 19(4), December 2005: 67-92.

Mayer, Christopher. "Taxes, Income Distribution, and the Real Estate Cycle: Why All Houses Don't Appreciate at the Same Rate." *New England Economics Review*. May 1993: 39-50.

Mayerhauser, Nicole and Marshall Reinsdorf. "Housing Services in the National Economic Accounts." Manuscript, Bureau of Economic Analysis, September 2007.

Mulligan, Casey B. "A Note on the Time-Elimination Method for Solving Recursive Dynamic Economic Models." NBER Technical Working paper no. 116, November 1991.

Mulligan, Casey B. and Luke Threinen. "Market Responses to the Panic of 2008." NBER working paper no. 14446, October 2008.

Poterba, James M. "Tax Subsidies to Owner-Occupied Housing: An Asset Market Approach." *Quarterly Journal of Economics*. 99, November 1984: 729-52.

Summers, Lawrence. "Taxation and Corporate Investment: A q Theory Approach." *Brookings Papers on Economic Activity*. 1981(1): 67-127.

Topel, Robert and Sherwin Rosen. "Housing Investment in the United States." *Journal of Political Economy*. 96(4), August 1988: 718-740.