

STICKY PRICE MODELS AND DURABLE GOODS*

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An increasing number of monetary business cycle models include durables. This paper argues that when sticky-price models include long-lived durables such as factories or houses, these durables dominate the behavior of the models. For example, varying the degree of price rigidity for durable goods has a much more dramatic effect on model outcomes than does varying the degree of price rigidity for nondurable goods. If long-lived durables have sticky prices, then even a small durables sector can cause the model to behave as though most prices were sticky, even if most other goods have flexible prices. On the other hand, long-lived durables with flexible prices contract during monetary expansions regardless of the degree of price rigidity in other goods. This tendency towards negative comovement for flexibly priced durables is robust. In an instructive limiting case, flexibly priced durables cause money to have no effect on aggregate output even though most prices in the model are sticky. Our key findings flow from the fact that the shadow value of long-lived durables is approximately unchanged by temporary shocks, such as monetary shocks. The near constancy of the shadow value generates powerful intertemporal mechanisms that are not present in models without durables.

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1. INTRODUCTION

Much of our understanding of sticky-price theories comes from models that abstract from capital, investment and durable goods.¹ Recent papers that focus on the quantitative performance of sticky-price models have explicitly included purchases of durables as an important element, either in the form of productive capital or in the form of consumer durables.² The addition of a durable goods sector is a critical extension of the earlier models both because of the dominant role that investment plays in the conventional understanding of monetary policy and because empirically, the output of long-lived durable goods (most notably housing) changes dramatically following monetary policy disturbances. In contrast, there are only small changes in the production of nondurables.³

This paper demonstrates, both analytically and with numerical simulations, that the incorporation of long-lived consumer or producer durables in sticky-price models fundamentally changes their nature in a way that has not yet been fully appreciated. Careful analysis of a two-sector sticky-price model with long-lived durables reveals that the pricing of these goods is central to the behavior of the model. By contrast, price rigidity in the nondurable goods sector is much less important.

The behavior of aggregate production depends critically on whether the durable goods have sticky prices. If the prices of long-lived durables are sticky, the model will behave as though most prices were sticky even if most other goods are in fact flexibly priced. In contrast, if the durables have flexible prices, then there is a strong tendency for these sectors – which respond so procyclically in the data - to contract following a monetary expansion. We present a striking example in which flexible durables prices

¹ The culmination of this literature is set out in Woodford [2003]. Models that restrict attention to nondurables are still prevalent in the sticky-price literature. See for instance Clarida, Gali and Gertler [1999], Dotsey, King and Wolman [1999], Golosov and Lucas [2005], and McCallum and Nelson [1999].

² See among others Altig *et al.* [2005], Chari, Kehoe and McGrattan [2000], Christiano, Eichenbaum and Evans [2003], and Dotsey and King [2001]. Kimball [1995] was a forerunner of these models.

³ Barsky, House and Kimball [2003] present a detailed description of the reaction of durables and nondurables to large monetary shocks (Romer dates).

imply something very close to monetary neutrality for overall output and prices, even though the bulk of GDP consists of sticky-price nondurables. In this instructive limiting case, the contraction of the flexibly priced durables sector exactly offsets the expansion in nondurable goods, leaving GDP unchanged.

The presence of long-lived durable goods also has implications for the behavior of other economic variables in response to monetary shocks. We show that, regardless of the degree of price rigidity in the two sectors, the real interest rate in terms of durables is essentially constant. As a result, changes in the nominal interest rate are purely a reflection of inflation in durable goods prices. We also demonstrate that consumption of nondurables varies if and only if there is a change in the relative price of durables and nondurables. If the relative price is unchanged then production of nondurables is unchanged regardless of how sticky their prices are.

All of these results flow from the observation that the shadow value of a long-lived durable (a durable with a very low depreciation rate) is approximately unchanged in the wake of a monetary policy shock. Because the shadow value of a long-lived durable reflects expected service flows over a long horizon, it does not react to disturbances that have only temporary effects on the economy. The near constancy of the shadow value implies that consumers and firms are nearly indifferent to the timing of durable goods purchases. Equivalently, the intertemporal elasticity of substitution for purchases of these goods is nearly infinite. Even modest changes in the intertemporal relative price of these goods would cause pronounced swings in production. In contrast, nondurables are subject to the consumption smoothing logic of the permanent income hypothesis. The PIH leaves little room for consumers to substitute intertemporally and therefore nondurables play a much smaller role in aggregate fluctuations.

Our findings have important implications for sticky-price research. First, concluding that sticky-prices are of limited importance because so many goods have flexible prices is incorrect. In our model, even if all nondurable goods prices were flexible, money would continue to cause pronounced changes in economic activity provided that the durables had sticky prices. Similarly, calibrating models using data on price rigidity for nondurables simply because nondurables are the lion's share of GDP is also potentially misleading. The pricing of durables dictates the aggregate behavior of

our model regardless of the pricing and demand structure of the nondurables. If, as our analysis suggests, durables are the most important element in sticky-price models, researchers must devote more effort to empirical investigation of the pricing of these goods. While there is an abundance of evidence pertaining to the price rigidity of nondurables, there is much less evidence on the degree of price rigidity for long-lived durables.⁴

2. THE MODEL

We analyze a two-sector sticky-price model. In the model, consumers get utility from both durable and nondurable goods. The model allows each sector to have different degrees of price rigidity.⁵ We emphasize that while we model the durable as a consumer good, our results continue to hold if the durable is productive capital. The pertinent feature of the durable is its low depreciation rate (i.e., its longevity). The ultimate use of the good is less important.

2.1 HOUSEHOLDS

Consumers get utility from nondurable and durable consumption and get disutility from working. The household owns a fixed stock of productive capital K . Let C_t be the nondurable good and let D_t be the stock of the durable. X_t denotes purchases of new durables and N_t is labor supplied at date t . Households maximize

$$E_t \left[\sum_{i=0}^{\infty} \beta^i (u(C_{t+i}, D_{t+i}) - v(N_{t+i})) \right] \quad (1)$$

subject to the nominal budget constraint

⁴ Most empirical research on sticky prices focuses on nondurables. The most comprehensive recent study is Bils and Klenow [2004]. While their study includes goods that are durables in the NIPA accounts (cars, washing machines, etc.) it does not include long-lived durables such as houses and factories. Other examples include Cecchetti's 1986 study of magazine prices, Slade's 1998 study of supermarket pricing, Levy and Young's 2004 study of Coca Cola prices, and Kashyap's 1995 study of L.L.Bean catalogues. See also Aguirregabiria [1999], Klenow and Kryvstov [2005], Lach and Tsiddon [1992, 1996], Levy, *et al.* [1997], Pesendorfer [2002], Slade [1998], Tommasi [1993] and Warren and Barsky [1995].

⁵ Previous papers that study models with flexible and sticky price sectors include Blinder and Mankiw [1984], Ohanian and Stockman [1994], Ohanian, *et al.* [1995], and Bils, Klenow and Kryvstov [2003]. Only Ohanian *et al.* [1995] includes a durables sector. Their simulations are consistent with our results. The comment on Ohanian *et al.* by Leahy [1995] hints at some of the logic behind the results but leaves several questions unanswered – particularly why the overall output effect is so close to zero in their model.

$$P_{c,t}C_t + P_{x,t}X_t + M_t \leq W_tN_t + \Pi_t + T_t + (1+i_{t-1})S_{t-1} - S_t + M_{t-1} + R_tK,$$

and the accumulation equation for the durable,

$$D_t = X_t + D_{t-1}(1-\delta). \quad (2)$$

Here $P_{x,t}$ and $P_{c,t}$ are the nominal prices of the durable and the nondurable, W_t is the nominal wage rate and R_t is the nominal rental price of capital. Π_t is profits returned to the consumer through dividends, T_t is lump-sum nominal transfers, M_t is nominal money balances held at time t , S_t is nominal savings and i_t is the nominal interest rate.

Define $MU_t^C \equiv \partial u(C_t, D_t) / \partial C_t$ as the marginal utility of an additional unit of nondurable consumption and $MU_t^D \equiv \partial u(C_t, D_t) / \partial D_t$ as the marginal utility of the service flow from an additional unit of the durable at time t respectively. Let γ_t be the Lagrange multiplier on the stock of durables (equation (2)). The first order conditions for C , N and X require

$$\frac{MU_t^C}{\gamma_t} = \frac{P_{c,t}}{P_{x,t}} \quad (3)$$

$$v'(N_t) = \frac{W_t}{P_{x,t}} \gamma_t = \frac{W_t}{P_{c,t}} MU_t^C. \quad (4)$$

and

$$\gamma_t = MU_t^D + \beta(1-\delta)E_t[\gamma_{t+1}]. \quad (5)$$

2.2 FIRMS

Final goods are produced from intermediates. Using lower-case letters to denote variables for individual intermediate producers we can write the production functions as

$$X_t = \left[\int_0^1 x_t(s)^{\frac{\varepsilon-1}{\varepsilon}} ds \right]^{\frac{\varepsilon}{\varepsilon-1}} \quad \text{and} \quad C_t = \left[\int_0^1 c_t(s)^{\frac{\varepsilon-1}{\varepsilon}} ds \right]^{\frac{\varepsilon}{\varepsilon-1}}, \quad (6)$$

where $\varepsilon > 1$. Final goods producers are competitive while intermediate goods producers have monopoly power. Free entry into the production of final goods implies that

$$P_{j,t} = \left[\int_0^1 p_{j,t}(s)^{1-\varepsilon} ds \right]^{\frac{1}{1-\varepsilon}}, \quad \text{for } j = X, C. \quad (7)$$

The demand for the intermediate goods is given by

$$x_t(s) = X_t \left(\frac{P_{x,t}(s)}{P_{x,t}} \right)^{-\varepsilon} \quad \text{and} \quad c_t(s) = C_t \left(\frac{P_{c,t}(s)}{P_{c,t}} \right)^{-\varepsilon}. \quad (8)$$

Intermediate goods firms maximize the discounted value of profits for their shareholders (the households) and thus discount profits in period $t+i$ by $\beta^i MU_{t+i}^C$. Each intermediate goods firm has a constant returns to scale production function

$x_t(s) = F(k_{x,t}(s), n_{x,t}(s))$ and $c_t(s) = F(k_{c,t}(s), n_{c,t}(s))$ where $n_{j,t}(s)$ and $k_{j,t}(s)$ are employment and capital in firm s in industry $j = C, X$ at time t . Intermediate goods firms take input prices as given and choose capital and labor to maximize profits.

Because the production functions have constant returns to scale, and because capital and labor can flow freely across firms, firms will choose the same capital-to-labor ratios. Thus within any industry

$$\frac{k_{j,t}(s)}{n_{j,t}(s)} = \frac{K_j}{N_{j,t}} = \frac{K}{N_t},$$

where $K_j = \int k_{j,t}(s) ds$ and $N_{j,t} = \int n_{j,t}(s) ds$ are capital and labor used in industry $j = C, X$.⁶

The nominal marginal cost of production is the cost of hiring an additional unit of a productive input times the number of inputs required to produce an additional unit of output. With labor and capital free to flow across industries and constant returns to scale production functions, all firms have the same nominal marginal cost of production. To be specific, $MC_t = W_t [f(N_t)]^{-1}$ where $f(N_t) = \partial F(K, N_t) / \partial N_t$ is the marginal product of labor in any firm.

Since the elasticity of demand is fixed, firms desire constant markups over nominal marginal costs; the desired markup is $\mu = \frac{\varepsilon}{\varepsilon-1} > 1$. Any deviation of the markup from its desired level comes from nominal rigidities. Firms with flexible prices simply charge $P_{j,t} = \mu MC_t$ and thus maintain their markup. Firms with sticky prices occasionally endure periods when the markup deviates from its desired level.

⁶ Here we are treating capital as unproduced and constant at K . When productive capital can itself be produced, the high stock/flow ratio that arises for long-lived capital implies that K_t moves slowly enough that $K_t \approx K$ for any short-lived shock, where K is the steady-state level of capital.

We model sticky prices with a Calvo mechanism. Let θ_j be the probability that a firm in industry j cannot reset its price in a period. Thus, each period $1 - \theta_j$ firms reset their prices while θ_j firms keep their prices from the previous period. Whenever possible, firms reset prices to maximize expected profits. Let the reset price in industry j be $p_{j,t}^*$. The optimal reset prices are then

$$p_{j,t}^* = \mu \frac{\sum_{i=0}^{\infty} (\theta_j \beta)^i E_t [MU_{t+i}^j P_{j,t+i}^{\varepsilon-1} MC_{j,t+i} j_{t+i}]}{\sum_{i=0}^{\infty} (\theta_j \beta)^i E_t [MU_{t+i}^j P_{j,t+i}^{\varepsilon-1} j_{t+i}]}, \quad (9)$$

so that final goods prices evolve according to

$$P_{j,t} = \left[\theta_j (P_{j,t-1})^{1-\varepsilon} + (1 - \theta_j) (p_{j,t}^*)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \quad (10)$$

for each industry $j = C, X$.

2.3 Money Demand and Market Clearing

We assume that money demand is proportional to nominal GDP

$$M_t = P_{c,t} C_t + P_{x,t} X_t.$$

Money is injected into the economy through lump sum transfers T_t . We assume the money supply follows a random walk.

$$M_t = M_{t-1} + \xi_t, \quad (11)$$

where ξ_t is a mean zero *i.i.d.* disturbance.

We construct real GDP Y_t as $Y_t \equiv P_c C_t + P_x X_t$ where P_c and P_x are steady-state prices for the nondurable and durable good. The aggregate price level (the GDP deflator) is then nominal GDP divided by real GDP.

Finally, labor market and capital market equilibrium require,

$$N_t = N_{x,t} + N_{c,t} \quad \text{and} \quad K = K_{x,t} + K_{c,t}. \quad (12)$$

This completes the specification of the model.

3 THE ROLE OF DURABLES IN STICKY PRICE MODELS

In this section, we show that the behavior of sticky price models depends crucially on durable goods and in particular on how durable goods prices are set. To introduce our

main results, we begin in Section 3.1 by numerically simulating some illustrative special cases of the model. Following the numerical illustrations, in Section 3.2 we present an analytical treatment that provides insight into the underlying mechanisms. In Section 3.3 we study the sensitivity of the quantitative results to variations in—among other things—the share of the durable goods sector and the relative degree of price rigidity across sectors.

3.1 SIMULATIONS

Figure 1 presents four simulations of the model under various assumptions. The durable in the simulations has an annual depreciation rate of 5% and the household discounts the future at 2% per year (i.e., $\delta = 0.05$ and $\beta = 0.98$). As a benchmark, θ_c and θ_x are set to imply a six-month half-life of exogenous price rigidity. We compute the equilibrium of a linear approximation of the model in the neighborhood of its non-stochastic steady state using the following parametric functions for u , v and F :

$$u(C_t, D_t) = \frac{\sigma}{\sigma-1} \left[(\psi_c C_t^{1-\frac{1}{\rho}} + \psi_d D_t^{1-\frac{1}{\rho}})^{\frac{\rho}{\rho-1}} \right]^{\frac{\sigma-1}{\sigma}}, \quad v(N_t) = \phi \frac{\eta}{\eta+1} N_t^{\frac{\eta+1}{\eta}}, \text{ and } F(k, n) = k^\alpha n^{1-\alpha}.$$

We use the following parameter values: the Frisch labor supply elasticity (η) is 1, σ and ρ are both 1 so the within-period utility function is simply $\psi_c \ln C_t + \psi_d \ln D_t$. We set ε to generate a desired markup of 10%, and ψ_c and ψ_d are set to give a steady-state nondurable share of .75 in GDP. Capital's share (α) is set to 0.35. We focus on the reaction of the model to a permanent unanticipated increase in the money supply of 1.00%. Each of the nine panels in Figure 1 shows the reaction of a single variable under four different scenarios: the model with nondurables only, the model with symmetric price rigidity in both sectors, the model with sticky prices in the durables sector alone, and the model with sticky prices in only the nondurables sector.

Nondurable Goods Only

Because many New Keynesian models omit durables entirely, we begin with the special case in which there are only nondurables. The time paths for this case are shown by the thin dotted lines. The top-left panel shows the change in production. Because prices are sticky in the short run, output immediately increases by exactly 1.00%. (The plots are

calculated based on a period equal to $1/100^{\text{th}}$ of a year; for convenience, quarters are marked on the axis). In the first quarter after the shock, GDP is above trend by 0.74% (this is the time averaged response of GDP over the first quarter). The middle-left panel shows the evolution of prices. Over time, prices adjust and production, employment and consumption all return to their steady state levels. The lower-left panel shows that the nominal interest rate is flat while the lower-center panel shows that the real interest rate falls below trend.⁷

In short, in the model with only nondurables, monetary policy shocks have very conventional effects: Real interest rates fall; production and employment temporarily rise, and prices slowly adjust to their new long-run levels.

Durable and Nondurable Goods.

Now we augment the model with a sector that produces long-lived durables. As before, prices are equally sticky throughout the economy. The equilibrium reaction to the money shock for this case is indicated with the thick solid line. The panels in the top row show GDP, nondurable consumption and the production of the durable good. As before, output increases in the short run and then slowly falls back to its steady state level. In the first quarter after the shock, GDP is above trend by 0.78%. In contrast to the previous case however, the increased production is accounted for entirely by production of the durable – production of the nondurable is essentially unchanged.⁸ The panels in the second row show that once again prices rise slowly. Because nominal marginal costs are equated across sectors, prices in the two sectors are the same. The bottom row shows the reaction of interest rates. As often occurs in models with durables, a monetary expansion raises the nominal interest rate immediately. Because prices are the same across industries, the real interest rate is the same for nondurables and durables. Unlike the case with nondurables alone, this example exhibits no change in the real rate of return.

Clearly, the introduction of the durable good has fundamentally changed the behavior of the model. The importance of the durables sector is even more evident if we allow for differences in price rigidity across sectors.

⁷ If σ were below one, the nominal rate would fall as well as the real rate.

⁸ In the first quarter, nondurable production rises by 0.03% while durable production increases by 3.01%.

Durable Goods with Flexible Prices

The thin solid line shows the reaction of the model when the durable goods have flexible prices while the nondurables have sticky prices. As before, the shock is a permanent 1.00% increase in the money supply. Because the sticky price sector is such a large part of the economy, it is natural to think that GDP will again react sharply to the monetary injection. Yet the figure shows that even though the sticky price sector is 75% of GDP, money has essentially no effect on employment and production. In the first quarter following the shock, output rises by 0.03% (three hundredths of one percent) while the aggregate price level jumps by 1.00%. Surprisingly, even though most prices are sticky, money appears to be neutral with respect to aggregate output. Just as it would in a flexible price model, the aggregate price level moves one-for-one with changes in the money supply.

Within the durable and nondurable goods industries, production and prices move in opposite directions. In the first quarter, production of the durable falls by 7.92% while nondurable consumption rises by 2.68%. These offsetting movements leave total production unchanged. Also, while nondurables prices rise slowly, the price of durables overshoots its eventual level. Note that both the nominal interest rate and the own real interest rate for nondurable consumption fall.

Durable Goods with Sticky Prices

Finally, the thick dotted line shows the model's reaction when the durable goods have sticky prices while the nondurable goods have flexible prices. Even though only 25% of GDP has sticky prices, the overall qualitative reaction of the model is similar to that seen when all prices were sticky. Output rises substantially following the shock. In the first quarter, GDP increases by 0.32% – this is roughly half of the increase we saw in the case where all prices were sticky. The aggregate price level jumps up after the shock and then slowly converges to the higher level. In contrast to the case with flexible durable goods prices, neither price overshoots. As in the model in which all prices were equally sticky, real interest rates show almost no change and the nominal interest rate rises. While the

model has been deprived of seventy five percent of its price rigidity, it retains the basic features of the pure sticky price model in response to monetary shocks.

3.2 ANALYTICAL DISCUSSION

The numerical examples demonstrate the importance of durable goods in the model.

Whether durables have sticky prices is particularly important in determining the model's behavior. Indeed, the long-lived durables dominate the model, a fact that is revealed in a number of guises. Some of the more interesting properties of the model with long-lived durables are: (1) Aggregate GDP reacts to the money shock only when long-lived durables have sticky prices. (2) When durables prices are flexible, a monetary expansion causes a large contraction of the durables sector. (3) When prices are equally sticky in the two sectors, nondurables consumption does not respond to the money shock, and (4) the real interest rate in terms of durables does not react to money shocks (or other temporary shocks) and as a result, the nominal interest rate is essentially a reflection of inflation in the durable goods price. These results all flow from a common property of highly durable goods: the near constancy of the shadow value of long-lived durables.

The Shadow Value of Long-Lived Durable Goods

The reason that durable goods sectors exert so much influence in sticky-price models is that the intertemporal elasticity of substitution for purchases of durables is inherently high, and hence the output of the durables sector responds sharply to changes in intertemporal relative prices. To show this clearly, we appeal to an approximation that holds arbitrarily well for durables with sufficiently low depreciation rates. The limiting approximation implies that the intertemporal elasticity of substitution for purchases of durable goods is in fact infinite. A good with this property can be thought of as an *idealized durable*. The question of just how long-lived the durables have to be for the approximation to be accurate – or equivalently, for what real-world durables is the theory most relevant - will be discussed at the end of Section 3.3.

The shadow value of any durable consumer good can be written as the present value of marginal utilities of the service flow of the durable, discounted at the subjective rate of time preference and the rate of economic depreciation:

$$\gamma_t = E_t \left[\sum_{i=0}^{\infty} [\beta(1-\delta)]^i MU_{t+i}^D \right]. \quad (13)$$

Two observations together guarantee that for long-lived durables γ_t will be largely invariant to shocks with short-lived effects. First, durables with low depreciation rates have high stock-flow ratios. In our model, the steady state stock-flow ratio is $1/\delta$. A high stock-flow ratio implies that even relatively large changes in the production of the durable over a moderate horizon have small effects on the total stock. Therefore, changes in the production of the durable cause only minor changes in the service flows. This limits the degree to which γ_t can change.

Second, if δ is sufficiently low, γ_t is heavily influenced by the marginal utilities of service flows in the distant future. Because the effects of the shock are temporary, the future terms in (13) remain close to their steady state values. Thus even if there were significant changes in the first few terms of the expansion, they would have a small percentage effect on the present value as a whole. Note that this point implies that the model can accommodate even substantial temporary changes in the marginal utility of the service flow (due for instance to complementarities with other variables that fluctuate in the short run) and still imply a nearly invariant shadow value.⁹

Together, these two observations suggest that it is reasonable to treat the shadow value of sufficiently long-lived durables as roughly constant in the face of a monetary disturbance (or indeed any short-lived shock). That is, for a long-lived durable, we can set $\gamma_t \approx \gamma$. This approximation is equivalent to saying that the demand for durable goods displays an almost infinite elasticity of intertemporal substitution. Even a small rise in the price of the durable today relative to tomorrow would cause people to delay their purchases. As we will see below, this limiting property of an idealized durable has many consequences for the model.

⁹ The determining factor for the magnitude of both of these effects is the persistence of the shock relative to the longevity of the durable. See House and Shapiro (2005) for an application of this idea to the analysis of temporary tax policies.

Flexible Durables Prices and Aggregate Neutrality

The simulations suggested that when the durables had flexible prices, money was essentially neutral at the aggregate level. The monetary disturbance produced a negligible change in overall production and the aggregate price level jumped immediately to its new long-run level. We are now in a position to show analytically how this follows from the near constancy of the shadow price of long-lived durables in the face of temporary shocks.

If durable goods prices are flexible, the CES structure implies that their prices are a constant markup over nominal marginal costs: $P_{x,t} = \mu W_t [f(N_t)]^{-1}$. Substituting this into the first order condition (4) and using $\gamma_t \approx \gamma$ we get

$$v'(N_t) = \frac{W_t}{P_{x,t}} \gamma_t \approx \frac{\gamma}{\mu} f(N_t). \quad (14)$$

With γ and μ time-invariant, we have one equation in the one aggregate variable N_t . The level of employment that solves (14) is simply the steady state level of aggregate employment. Therefore neither employment nor total production changes following the shock, and money appears neutral with respect to GDP and the aggregate price level. This is true regardless of how much price rigidity there is in the nondurables sector, regardless of the ratio of nondurables to durables and regardless of the demand structure for nondurable goods.

Neutrality will emerge in our model whenever the durable goods prices are flexible and one of the following conditions is satisfied: (i) production functions have constant returns to scale and factors of production can flow from one industry to another; or (ii) labor can flow across industries and the marginal product of labor in the durable goods sector is constant.

Negative Comovement of Flexibly Priced Durable Goods

Of course, conditions (i) or (ii) are not satisfied in every sticky-price model and are not likely to hold in reality. If we instead assume that the production functions have diminishing marginal products of labor, as they will when capital is immobile between sectors, (14) is replaced by

$$v'(N_t) \approx \frac{\gamma}{\mu} f_x(N_{x,t}). \quad (15)$$

In this case we cannot conclude that aggregate employment will be unchanged.

However, if aggregate employment rises, then $v'(N_t)$ rises, reflecting the fact that workers are being drawn up their labor supply curves. To maintain equality, the right hand side of (15) must also rise. To increase the marginal product of labor, $f_x(N_{x,t})$, employment in the durables sector must fall. Thus, employment and output in the durable goods industry must exhibit negative comovement with aggregate employment and output whenever the durable has a flexible price.¹⁰

Unlike the neutrality property, which holds only in special circumstances, the tendency for flexibly priced durables to comove negatively with total employment is robust. Aside from the additive separability of employment,¹¹ deriving (15) required only that the good was a long-lived durable with flexible prices and that marginal costs increase with aggregate production (which comes from the increasing marginal disutility of work). Among other things, the negative comovement of flexibly priced durables is independent of the demand structure of other goods in the economy, the form of price rigidity in the sticky-price sectors, and the money supply rule. Thus, for durable goods to expand together with aggregate employment, it is *necessary* that they have some form of price rigidity.¹²

¹⁰ If there is a separate labor supply curve for each industry, $v'(N_t)$ in (15) would be replaced with $v'_x(N_{x,t})$, implying that the output in the durables sector is acyclical.

¹¹ Because the stock of the durable changes so slightly over the business cycle, nonseparability between labor and the durable good itself is not important. If labor and the *nondurable* were complementary then some of our results could change. In particular, if labor and nondurable consumption were complements, then increasing the quantity of nondurables shifts labor supply out, tempering (but for plausible parameter values not eliminating) the negative comovement of nondurables and flexibly priced durables.

¹² There is a close connection between aggregate employment and the real product wage in the durables sector. In fact, in the separable case there is a one-to-one correspondence between the two. Using the constant shadow value approximation, we can write (4) as $v'(N_t) = \frac{w_t}{P_{x,t}} \gamma_t \approx \frac{w_t}{P_{x,t}} \gamma$. That employment depends on the real product wage is not surprising. What is surprising is that it depends *only* on the real product wage for *durables*. Since the shadow value of the durable is fixed, changes in the real product wage translate directly into changes in employment, irrespective of changes elsewhere in the economy.

Implications for Nondurable Goods

The constant shadow value of the durable also has implications for the nondurable good. Equation (3) says that households optimally equate the marginal utility per dollar across goods and establishes a link between the price ratio $P_{c,t} / P_{x,t}$ and the marginal utility of the nondurable $MU_t^C(C_t, D_t)$. Because the durable is long-lived, the stock-flow ratio is high and we can treat the stock D_t as roughly constant ($D_t \approx D$). In this case, (3) says

$$MU_t^C(C_t, D) \approx \frac{P_{c,t}}{P_{x,t}} \gamma.$$

Thus, there is a one-to-one relationship between the relative price $P_{c,t} / P_{x,t}$ and production of the nondurable. If the relative price is high then nondurable consumption will be below trend and vice versa. In the benchmark case with equally sticky prices, the price ratio is constant so that $MU_t^C(C_t, D) \approx \gamma$ and nondurable consumption did not change—even though overall output increased substantially. Observing that some nondurables with very sticky prices do not react to monetary policy is therefore entirely consistent with sticky-price theories.

The Nominal Interest Rate and the Real Rate of Return on Durable Goods

Because nominal interest rates are so prominent in the conventional understanding of monetary policy, they have received considerable attention in sticky-price theories. Surprisingly, in a sticky-price model with highly durable goods, the nominal interest rate is almost entirely a reflection of inflation in durable goods prices. Again, this flows directly from the near constancy of the shadow value of highly durable goods and is a robust property of sticky price models.

To see this, recall that the real rate of return is the nominal interest rate divided by price growth. While real rates of return can vary across commodities and over time, for a long-lived durable, the constancy of the shadow value implies that the own real rate of return is approximately constant. To be specific, the real rate of return on durables satisfies $\gamma_t = \beta E_t[\gamma_{t+1}(1 + r_{x,t+1})]$. Because $\gamma_t \approx \gamma$, the expected real rate of return on

durable goods must remain approximately constant following a monetary shock. Using the definition of the real rate of return, we conclude that

$$(1+i_t) \approx \frac{1}{\beta} E_t \left[\frac{P_{x,t+1}}{P_{x,t}} \right]. \quad (16)$$

Thus, if the durable is sufficiently long-lived, the nominal interest rate must reflect expected inflation in the durable goods sector. Put differently, the nominal interest rate can fall only if there is an expected *deflation* in durable goods prices.

Durable Productive Capital

While the precise results in Figure 2 hold only for the two-sector model presented above, we emphasize that many of the results are robust to a wide range of variations in the structure of the model. One seemingly fundamental modification is if the durable is productive capital instead of a consumption good. In fact, however, the behavior of the model when the durable is productive capital is extremely close to the behavior when the durable is a consumer good. The reason is that the shadow value of the durable (the shadow value of capital) is again approximately unchanged by the shock. In this case, the shadow value is

$$\gamma_t = E_t \left[\sum_{i=0}^{\infty} [\beta(1-\delta)]^i MP_{t+i}^K \right],$$

where MP_{t+i}^K is the marginal product of capital in period $t+i$. As before, because the capital stock is relatively unchanged, and because the future terms in γ_t are unaffected by the shock, γ_t is approximately constant. The remaining equations are unchanged.¹³

¹³ In an appendix available online, we present a model with productive capital. The impulse responses are almost the same as those in Figure 1. In addition to productive capital, investment adjustment costs are also common in such models. Investment adjustment costs further inhibit changes in the stock of the durable and do not affect the constancy of γ_t . Thus many of our results survive the addition of such adjustment costs, though in modified form. Flexibly priced durables still comove negatively with aggregate production. The determination of the nominal interest rate, the production of nondurables, and the aggregate supply of labor depend in this case on the price inclusive of adjustment costs.

3.3 SENSITIVITY ANALYSIS

The model above considers a long-lived durable good with an annual depreciation rate of 5%. The durable goods sector was 25% of GDP and prices were either sticky or fully flexible. In this section, we consider how the results change as we vary the degree of price rigidity, the size of the two sectors, and the depreciation rate for the durable good.

Relative Price Flexibility

Here we consider mixed cases in which both prices are sticky but one is relatively more flexible than the other. Figure 2 shows the equilibrium reaction of output, consumption, and durable goods production as we vary the degree of exogenous nominal rigidity in the two sectors. The upper row (Figure 2.A) considers variations in the Calvo parameter (θ_c) for the nondurable goods sector. At one extreme is the baseline setting which implies roughly 1.3 price changes per year. (This corresponds to a 6-month half-life.) At the other extreme, θ_c is set to imply 52 price changes per year. The Calvo parameter for the durables (θ_x) is held constant. It is surprising how little this parameter influences the model over this range. While it is clear that production responds more when nondurables have sticky prices, the magnitude and general profile of the impulse responses when nondurables reset prices once a year is roughly the same as when nondurables reset prices once every two weeks.

The lower panel (Figure 2.B) considers variations in the Calvo parameter for the durable goods sector. Clearly, changes in the price rigidity of durable goods have drastic effects on the equilibrium. High values of θ_x generate negative comovement between the production of durables and nondurables. Total production is also dramatically affected. If durable goods prices are reset once every month (12 changes per year), the equilibrium response of GDP is essentially gone after one quarter. Data from this model would suggest that GDP was white noise.

The Share of Sticky Price Goods

Figure 3 plots the percent change in GDP in the year after the shock as we vary the share of the sticky price sector. At the far left, no goods have sticky prices. At the far right, all

goods have sticky prices. The two lines distinguish the model with sticky durables prices (dashed line) from the model with sticky nondurables prices (solid line).

In each case, as the share of the sticky price sector drops, the output response gets smaller. When the sticky price goods are nondurables, however, the output response falls very rapidly. Even when 80% of GDP has sticky prices, the first quarter response of GDP is less than one fifth of the response when all prices are sticky. When the durables have sticky prices, the decline in the output response is more gradual. The output response when 20% of GDP has sticky prices is half the response when all prices are sticky. Output increases more when 10% of GDP are durables with sticky prices than when 90% of GDP consists of nondurables with sticky prices.

What is a Long-Lived Durable Good?

The limiting result says that in response to a transitory shock, the shadow value of the durable (γ_t) will be unchanged. This result holds exactly only for arbitrarily small δ (and small rates of time discount). How well will the result hold for higher but still plausible depreciation rates? Put differently, what real-world durable goods are close enough to the idealized durables that the theory pertains to?

Note first that there is a trade-off between the durability of the good and the degree of price rigidity in the two sectors. Given any θ_c and θ_x , there is a δ sufficiently small (and a β sufficiently close to 1) such that the change in γ_t is arbitrarily close to zero. Alternatively, given δ , there is a rate of price adjustment that is sufficiently fast that the approximation is again arbitrarily accurate. The intuition for this tradeoff is natural: The change in the shadow value comes from short-run changes in the marginal utility of the service flow of the durable. If prices adjust quickly, then the effects of price rigidity are very brief. As a result, changes in complements (or substitutes) to the durable are very short-lived, and the change in the stock of the durable itself is very small.¹⁴

¹⁴ Only the ratios of the rates matters for the magnitude of the changes in the variables. Doubling all rates for instance (the rate of price adjustment, the rate of depreciation and the rate of time preference), will generate the same equilibrium paths except that the responses occur twice as fast. If price adjustment took twice as long, the initial responses would be the same as if the depreciation rate (and the subjective rate of time discount) doubled.

To demonstrate the accuracy of the approximation, Table 1 reports the immediate change in γ_t for several different rates of economic depreciation and durations of price rigidity under the assumption that prices are equally sticky in each industry. Table 1 also shows how the initial change is influenced by variations in the elasticity of substitution σ and the Frisch labor supply elasticity η .

Our baseline calibration (a six-month half-life of price rigidity and a five percent annual rate of depreciation) implies an initial change in γ_t of -0.032% (3.2 basis points). Thus, the change in the shadow value is only three hundredths of the initial change in GDP and the long-run change in prices. With more rapid rates of depreciation, the initial change in the shadow value is higher. For $\delta = 0.10$ the initial change in γ_t is -0.057% and for $\delta = 0.25$ the initial change in γ_t is -0.120%. Note that annual depreciation rates for housing or business structures are less than three percent. (See Fraumeni [1997].)

For shorter durations of price rigidity the approximation is even more accurate. If the half-life of price rigidity is three months or less then the approximation will be appropriate for durables with depreciation rates even as high as 25%. A three month half-life is greater price rigidity than that in Chari, *et al.* [2000], who calibrate their model to imply a half-life of price rigidity of roughly 1.5 months. Thus the shadow value of the durable in the Chari, *et al.* model (which is a capital good) is essentially constant.

The approximation is somewhat worse when the Frisch labor supply elasticity η is high and when the intertemporal substitution elasticity σ is low. If labor supply is very elastic the change in the durables stock is greater. At the same time, if σ is low enough, then even small changes in the stock of durables imply substantial changes in the marginal utility of the service flow.

4. CONCLUSION

Durable goods feature prominently in discussions of monetary policy. In the data, they are among the sectors that respond most to monetary policy. Because durables are perceived as highly interest sensitive, they also occupy a central position in our understanding of the monetary transmission mechanism. It is therefore somewhat surprising that durables have not received more direct attention in sticky-price models of

the business cycle. While sticky-price theories have assumed a leading role in monetary business cycle analysis, much of our understanding of these theories comes from models without durables. Papers that include durables focus primarily on the quantitative behavior of the model for particular specifications and have not isolated the special role played by the durable goods and the mechanisms underlying that role.

The behavior of sticky price models depends heavily on whether durable goods have sticky prices. If durable goods prices are sticky, then even a small durables sector can cause the model to behave as though most, or all, prices were sticky. If durable goods prices are flexible then the model exhibits perverse behavior. Flexibly priced durables contract during periods of economic expansion. The tendency towards negative comovement is quite robust and can be so strong as to dominate the aggregate behavior of the model. Durables also play a critical role in governing other economic variables in our model. All of our findings flow from the near constancy of the shadow value of long-lived durables. This property of highly durable goods holds regardless of the durable's ultimate use. For example, it holds for factories as well as houses.

Given the lack of direct empirical evidence of price rigidity for long-lived durables, together with the influence they have in sticky price models, it is important to investigate whether such price rigidity exists for these goods. One could argue for instance, that the sales prices for new homes are flexible. Houses are expensive on a per unit basis, and often require considerable customization. If menu costs or other impediments to price flexibility have important fixed components, it is natural to think they would be overcome and that prices would be negotiated. Indeed, many new homes are priced for the first time only after they have been built. Are we then to conclude that house prices are truly flexible? In our model, this would present a serious problem – housing would counterfactually contract during periods of economic expansion. It may be that rigidity in the pricing of housing and other large durables, if it exists, is due primarily to sticky wages or sticky intermediate goods prices. Other researchers (for instance Basu [1995] and Christiano *et al.* [2003]) have stressed the importance of sticky wages and sticky intermediate goods prices for entirely different reasons. To the extent that they impart endogenous price rigidity for long-lived durables, it is even more important to investigate such rigidities.

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TABLE 1: SENSITIVITY ANALYSIS

Half-Life of Price Rigidity	Depreciation Rate	Shadow Value (γ)									
		$\eta = .1$	$\eta = .5$	$\eta = 1$	$\eta = 5$	$\eta = 10$	$\sigma = .01$	$\sigma = .1$	$\sigma = .2$	$\sigma = .5$	$\sigma = 1$
1 month	$\delta = .001$	0.000	0.000	0.000	0.000	0.000	-0.004	-0.002	-0.001	-0.001	0.000
	$\delta = .01$	-0.001	-0.001	-0.002	-0.002	-0.002	-0.007	-0.005	-0.004	-0.003	-0.002
	$\delta = .02$	-0.001	-0.002	-0.003	-0.004	-0.004	-0.010	-0.008	-0.006	-0.004	-0.003
	$\delta = .05$	-0.002	-0.004	-0.005	-0.007	-0.008	-0.018	-0.014	-0.012	-0.008	-0.005
	$\delta = .10$	-0.004	-0.008	-0.010	-0.014	-0.014	-0.030	-0.025	-0.021	-0.015	-0.010
	$\delta = .25$	-0.009	-0.018	-0.023	-0.031	-0.033	-0.069	-0.057	-0.049	-0.034	-0.023
3 months	$\delta = .001$	0.000	-0.001	-0.001	-0.001	-0.001	-0.013	-0.005	-0.003	-0.002	-0.001
	$\delta = .01$	-0.002	-0.004	-0.005	-0.006	-0.007	-0.022	-0.016	-0.013	-0.008	-0.005
	$\delta = .02$	-0.003	-0.006	-0.008	-0.011	-0.011	-0.030	-0.024	-0.019	-0.012	-0.008
	$\delta = .05$	-0.007	-0.013	-0.016	-0.022	-0.023	-0.055	-0.045	-0.037	-0.025	-0.016
	$\delta = .10$	-0.012	-0.024	-0.030	-0.040	-0.042	-0.094	-0.078	-0.066	-0.045	-0.030
	$\delta = .25$	-0.028	-0.054	-0.066	-0.086	-0.091	-0.213	-0.176	-0.148	-0.101	-0.066
6 months	$\delta = .001$	-0.001	-0.001	-0.002	-0.002	-0.003	-0.026	-0.011	-0.007	-0.003	-0.002
	$\delta = .01$	-0.004	-0.007	-0.009	-0.013	-0.013	-0.045	-0.033	-0.026	-0.015	-0.009
	$\delta = .02$	-0.006	-0.012	-0.015	-0.021	-0.022	-0.061	-0.048	-0.039	-0.025	-0.015
	$\delta = .05$	-0.013	-0.026	-0.032	-0.043	-0.045	-0.110	-0.089	-0.074	-0.049	-0.032
	$\delta = .10$	-0.024	-0.046	-0.057	-0.075	-0.078	-0.190	-0.156	-0.130	-0.087	-0.057
	$\delta = .25$	-0.054	-0.100	-0.120	-0.152	-0.158	-0.429	-0.346	-0.286	-0.188	-0.120
1 year	$\delta = .001$	-0.001	-0.002	-0.003	-0.005	-0.005	-0.053	-0.021	-0.013	-0.006	-0.003
	$\delta = .01$	-0.007	-0.014	-0.018	-0.024	-0.026	-0.090	-0.066	-0.051	-0.030	-0.018
	$\delta = .02$	-0.012	-0.024	-0.030	-0.040	-0.042	-0.123	-0.095	-0.077	-0.048	-0.030
	$\delta = .05$	-0.026	-0.049	-0.061	-0.079	-0.083	-0.220	-0.177	-0.145	-0.095	-0.061
	$\delta = .10$	-0.047	-0.086	-0.104	-0.133	-0.138	-0.380	-0.305	-0.251	-0.164	-0.104
	$\delta = .25$	-0.101	-0.173	-0.202	-0.244	-0.252	-0.854	-0.662	-0.530	-0.331	-0.202
2 years	$\delta = .001$	-0.002	-0.005	-0.006	-0.009	-0.010	-0.105	-0.042	-0.025	-0.012	-0.006
	$\delta = .01$	-0.014	-0.028	-0.035	-0.046	-0.049	-0.179	-0.129	-0.099	-0.058	-0.035
	$\delta = .02$	-0.024	-0.046	-0.057	-0.074	-0.078	-0.245	-0.187	-0.149	-0.092	-0.057
	$\delta = .05$	-0.050	-0.091	-0.110	-0.139	-0.145	-0.437	-0.343	-0.277	-0.176	-0.110
	$\delta = .10$	-0.087	-0.151	-0.178	-0.217	-0.224	-0.754	-0.583	-0.466	-0.290	-0.178
	$\delta = .25$	-0.174	-0.272	-0.307	-0.352	-0.360	-1.682	-1.212	-0.922	-0.531	-0.307

The table gives the immediate reaction of the shadow value (γ) to a permanent 1.00% increase in the money supply assuming equally sticky prices in both the durable and non-durable goods sectors.

Figure 1

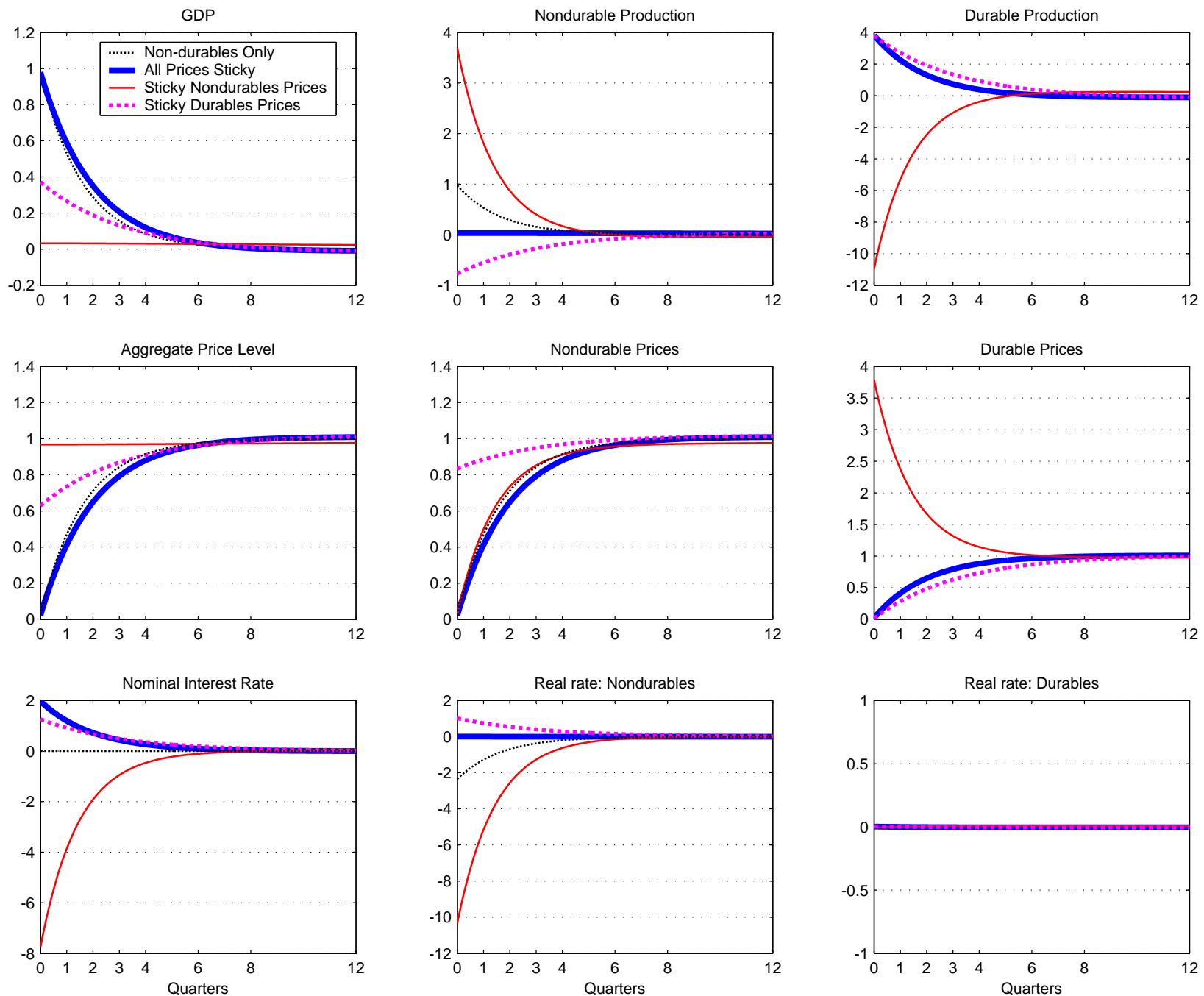


Figure 2

Figure 2.A: Changing the Nominal Rigidity for Non-durables

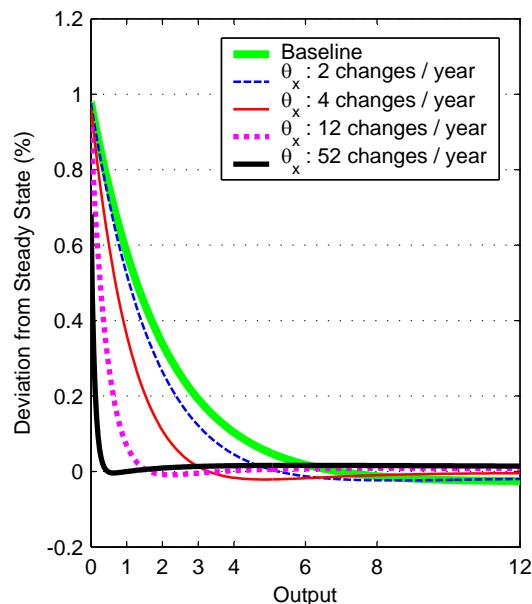
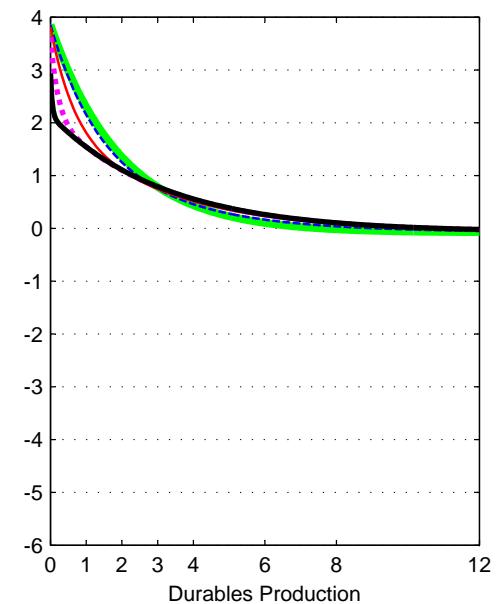
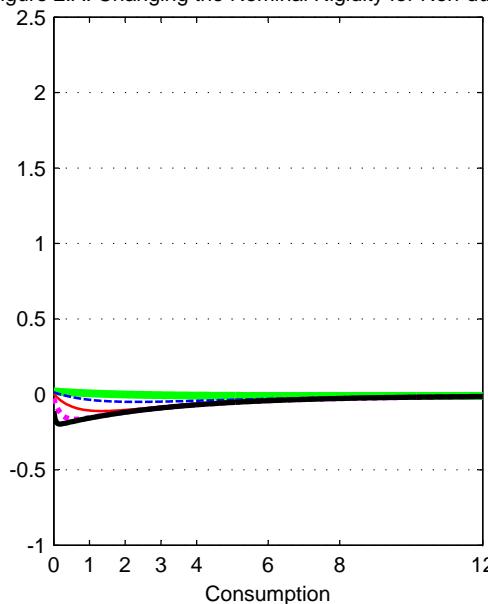
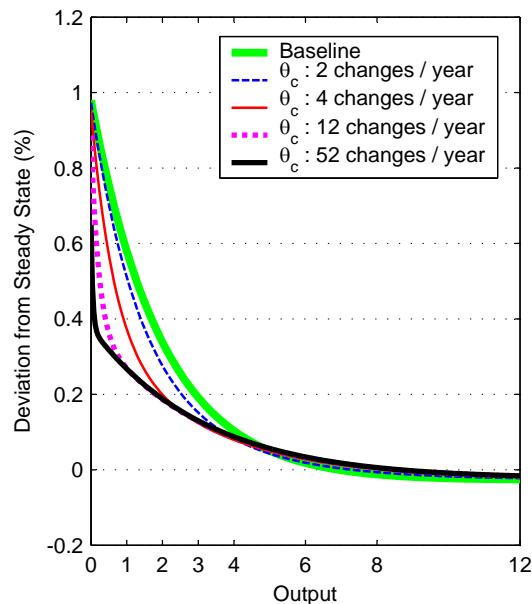


Figure 2.B: Changing the Nominal Rigidity for Durables

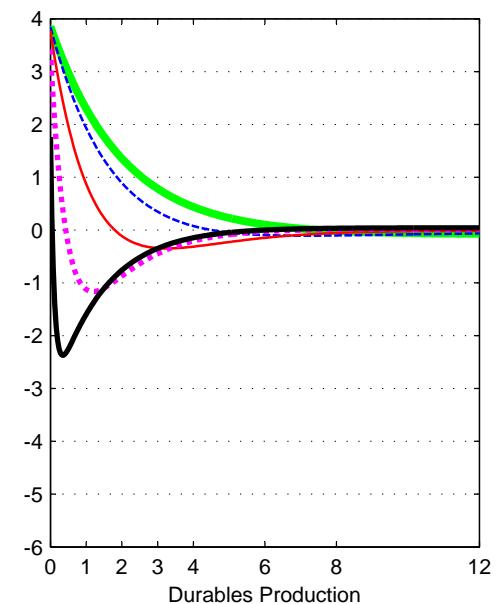
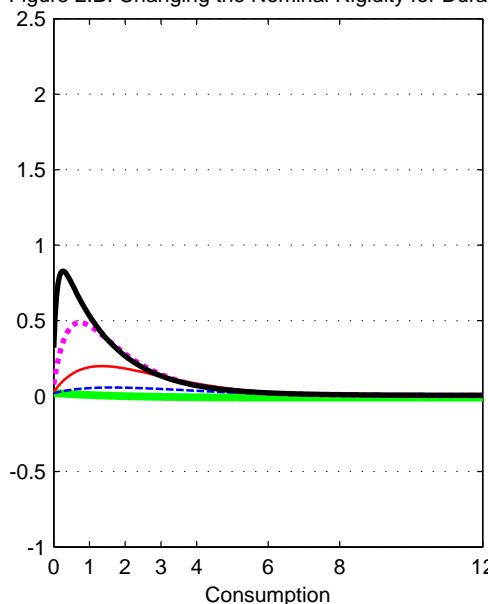


Figure 3

Variation in the Share of Sticky Price Goods in GDP

