STICKY PRICE MODELS AND DURABLE GOODS*

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ABSTRACT

This paper shows that there are striking implications that stem from including durable goods in otherwise conventional sticky price models. The behavior of these models depends heavily on whether durable goods are present and whether these goods have sticky prices. If long-lived durables have sticky prices, then even small durables sectors can cause the model to behave as though most prices were sticky. Conversely, if durable goods prices are flexible then the model exhibits unwelcome behavior. Flexibly priced durables contract during periods of economic expansion. The tendency towards negative comovement is very robust and can be so strong as to dominate the aggregate behavior of the model. In an instructive limiting case, money has no effects on aggregate output even though most prices in the model are sticky.

Keywords: Sticky prices, durables, comovement, neutrality.
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1. INTRODUCTION

Modern theories of the monetary business cycle typically attribute central importance to nominal rigidities. Much of our understanding of sticky-price models comes from one-sector models with symmetric firms using identical price-setting rules. Often these models abstract from durable goods and focus solely on the production of nondurables. In reality, large fluctuations in the production of durable goods are the most prominent feature of the response to monetary shocks. Empirically, business and residential investment fall sharply following a monetary contraction, while the production of nondurables falls only slightly. The assumption of symmetric price rigidity is also at odds with reality. To make a stark comparison, the price of a bottle of Coca Cola was fixed at five cents for a period of 70 years (see Levy and Young [2002]) while the prices of many agricultural commodities vary daily.

How important are these two types of heterogeneity? Does the presence of durables have important qualitative implications for the analysis of sticky price models? When some prices are sticky and some flexible, does the economy behave more like a flexible price model or more like a sticky price model?

The answers to these questions are related. We analyze a dynamic general equilibrium model with both sticky and flexible price sectors, and with both durable and nondurable goods. The aggregate behavior of the model depends crucially on which sectors have sticky prices. For the model to behave conventionally, the durable goods prices must be sticky. It is neither necessary nor sufficient for nondurables to have sticky prices. This is true even if the nondurables are the lion's share of GDP. Furthermore, in the presence of long-lived durables, the production of nondurables might not react to monetary policy – even when their prices are very rigid. Conversely, we show that durables with flexible prices pose serious problems for these models. Typically, production of flexibly priced durables falls when the economy expands. This result is extremely robust and is sharply at odds with the facts.[1] In some cases, this contrarian

[1] The mechanism that leads to the contrarian behavior of flexibly priced durables goods in our model is a particular instance of the more general comovement problem discussed by Murphy, Shleifer, and Vishny [1989]. They show that in multi-sector general equilibrium models, shocks that cause an expansion in one sector often lead to contractions in the others.

behavior can be so strong as to result in an equilibrium in which money has no influence on aggregate production or employment at all.

Why are durables so important? Durables have interesting and unique properties that flow directly from their longevity. The stock– and thus the associated shadow value – of durables is nearly constant over the modest horizon for which monetary disturbances might have real effects. As a result, the intertemporal elasticity of substitution for purchases of durables is naturally high. For durables with very low depreciation rates, such as housing and business structures, this elasticity is nearly infinite. Even modest changes in relative prices can lead to pronounced swings in the production of these goods. Moreover, these effects can be so large as to dominate the overall change in output. In contrast, nondurables are subject to the consumption smoothing logic of the permanent income hypothesis, leaving relatively little room for consumers to substitute intertemporally. Consequently, nondurables play a much smaller role in fluctuations of aggregate output.

Our findings have several implications. First, the fact that many goods have flexible prices is not a problem for sticky price models. Even if most prices are flexible, these models will continue to function "properly" as long as there is some nominal rigidity for durable goods. In addition, the observation that some goods with very sticky prices do not react to monetary policy is also not evidence against sticky price theories. Second, empirical evidence on price rigidity for durable goods is much more relevant than evidence for sticky prices in nondurable goods.[2] Third, because these models have difficulty accommodating long-lived durables with flexible prices, sticky wages or sticky intermediate goods prices may be necessary in New Keynesian theories. Because they impart endogenous price rigidity to goods whose final prices are flexible, wage rigidities can cause such sectors to increase production even when other costs rise.

[2] Most empirical research on sticky prices focuses on nondurables. Leading examples include Cecchetti's 1986 study of magazine prices, Slade's 1998 study of supermarket pricing, Levy and Young's recent 2002 study of Coca Cola prices, and Kashyap's 1995 study of L.L.Bean catalogues. Other papers that focus on nondurables include, Aguirregabiria [1999], Bils and Klenow [2003], Lach and Tsiddon [1992, 1996], Levy, Bergen, Dutta, and Venable [1997], Pesendorfer [1996], Slade [1996, 1998], Tommasi [1993] and Warren and Barsky [1995]. Blinder [1998] and Carlton [1986] are exceptions. The study by Bils and Klenow [2003] includes goods that are durables in the NIPA accounts (cars, washing machines, etc.) but they do not include durables like houses, factories, irrigation systems, etc. Thus they do not address the question of whether large long-lived durables have important nominal rigidities.

Previous papers that have studied models with flexible and sticky price sectors include Blinder and Mankiw [1984], Ohanian and Stockman [1994], Ohanian, Stockman, and Kilian [1995], and Bils, Klenow and Kryvstov [2003]. Only Ohanian *et al.* [1995] includes a durables sector. The simulations in their paper exhibit behavior that is consistent with our results. The comment on Ohanian *et al.* by Leahy [1995] hints at some of the logic behind these effects, but leaves several questions unanswered – particularly why the overall output effect is so close to zero in their model. Ohanian and Stockman [1994] allow for a variable intertemporal elasticity of substitution across two nondurable sectors. Because the naturally high intertemporal elasticity of substitution for durable goods spending plays a central role in our paper, to some extent, the economics in this paper parallels that in Ohanian and Stockman [1994].

The remainder of the paper is organized as follows. In section 2 we briefly document the pronounced behavior of the production of durable and nondurable goods following large changes in monetary policy. We also show that the relative price of durables to nondurables falls during monetary contractions. Section 3 presents a general framework for the analysis of durables in sticky price environments. Section 4 considers long-lived durables with perfectly flexible prices. This is an instructive limiting case which starkly reveals the importance of price rigidity in durables sectors. In section 5, we augment the analysis by numerically analyzing particular instance of the model. Section 6 concludes.

2. DURABLE GOODS AND MONETARY SHOCKS: STYLIZED FACTS

Before turning to the model, we examine prices and production of durable goods in periods surrounding contractionary shifts in monetary policy. Following a monetary tightening, the production of durables falls dramatically. Moreover, durable goods prices fall relative to the prices of nondurables following monetary contractions.

We focus on the economy's behavior following a few clear-cut, dramatic changes in monetary policy. Specifically, we use *Romer dates* as indicators of pronounced monetary tightness. The advantages of this approach are that our attention is drawn to the most drastic changes in monetary policy and that it allows for the possibility that important parts of monetary policy may be systematic.[3] This approach does have shortcomings. As Shapiro [1992] demonstrates, these monetary contractions are not exogenous. Romer dates tend to occur when inflation is high and rising and when unemployment is low. The "shocks" we identify are few in number and are not ranked by magnitude. Finally, there is reason to believe that Romer dates come too late to catch the inception of monetary tightenings[4] – a problem that is mitigated, however, by the approach taken below.

We document the behavior of several economic variables before and after the Romer dates.[5] For any variable x, we take averages of x_{t+j}/x_t given that t is a Romer date for j = -4, … 16. We compare this series with averages of x_{t+j}/x_t for all dates. The resulting series give us a window of observation on the economy during these episodes. We look before the date itself (i.e. before $j = 0$) to examine the behavior of the variable as the Romer date approaches. In addition, we suspect that Romer dates may lag the actual changes in policy.

Before proceeding to the results we should make a remark concerning the interpretation of the "trend" line in the figures. This is the average path of x_{t+j}/x_t for j = -4, … 16, averaged over all dates t. Statistically, this is the best predictor of the relative size of x, j periods before or after an arbitrary date t. Following a Romer date, some variables fall below "trend" and don't recover. This is because the timing of the Romer dates is endogenous. Typically Romer dates occur when the economy is "above trend". Thus, some of the response of a variable should be interpreted as simple mean reversion.

Figures 1.A and B show the average behavior of several economic variables in the quarters before and after a Romer date. The figures include bands to indicate one standard deviation around the point estimates. One thing to notice immediately is that the response of these variables is much more dramatic than responses following "shocks" in

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[3] An alternative would be to examine impulse responses to "identified" monetary policy shocks from a structural VAR. This has the advantage that, in the best case, it identifies the truly exogenous part of monetary policy. However, by excluding the systematic component of monetary policy, structural VARs miss the lion's share of the variation. Shocks identified by a VAR may not be monetary policy shocks at all, but rather the result of misspecification, omitted variables, or uninterpretable noise. For analysis using a VAR approach, see Erceg and Levin [2003].

[4] Bernanke and Mihov [1998] argue that Romer dates occur when their index describing the stance of monetary policy (the Bernanke-Mihov index) is at a trough, indicating that the actual change in monetary policy was made prior to the date.

[5] This approach goes back to Burns and Mitchell and was used recently in Doyle and Faust [2001].

a VAR. The main reason for this difference is that the "events" we examine are not small "shocks" to a stable monetary policy rule but rather are fundamental changes in policy. In a typical VAR system, a 1% shock to the federal funds rate reverts to a "normal" level quickly and induces only mild responses in GDP and the components of production. Following a Romer date, the federal funds rate continues to increase by roughly 4 points (400 basis points). In fact, the rise in the funds rate is more than this when we take into account the fact that interest rates were rising before the Romer event.

In Figure 1.A, we show that following a Romer date, durable goods sectors contract very sharply while nondurable goods (and overall GDP) do not. Relative to the reference period (date 0), housing starts fall by 33%. The trough occurs seven quarters after the Romer date. Starts remain more than 20% below the reference level for nine quarters (from t+4 until t+12). Real residential investment also falls substantially. After nine quarters, residential investment is 22% lower than it was in the reference date. Real automobile sales fall by 25%. They remain more than 10% below their reference level for eight quarters (from t+4 until t+11). Real durables purchases fall by 12.5% relative to the reference date. In contrast, the production of nondurables and GDP as a whole reacts much less. Real nondurables rise above trend immediately after the event and fall below "trend" after seven quarters. Real GDP does not fall relative to its level in the reference date. Relative to "trend" it falls by 6%.[6]

In addition to the effects on durables spending, there are also significant effects on the relative prices of durables and nondurables. The top four panels of Figure 1.B show the average responses of four relative prices following a Romer date. The price of new houses relative to the CPI for nondurables falls by 12% in comparison to the reference date.[7] The trough occurs nine quarters after the Romer date. The relative price of cars (measured as the CPI for new autos relative to the CPI for nondurables) falls by more than 6% relative to the base date and by 5% relative to the trend line. The price of durables relative to nondurables (measured by their CPIs) falls by 4.8% relative to the reference date and by 3.7% relative to trend.[8] The bottom two panels show the evolution

[6] Aggregate employment follows a similar pattern.
[7] This number is for the *median* house price. The number for the average house price is similar.
[8] While impulse responses to money shocks in identified VARs show strong responses of production of durables they do not exhibit the pronounced movement in relative prices. See Erceg and Levin [2003].

of the (nominal) average house price and median house price following a Romer date. Although these prices continue to rise, their rates of inflation drop immediately after the reference date.

To summarize, the production of durables responds significantly to changes in monetary policy while the production of nondurables does not. Moreover, the relative price of durable goods to nondurable goods appears to fall after a monetary contraction. In particular, housing starts fall by more than 30% and the price of new houses relative to nondurables falls by roughly 10%.

3. General Framework and Preliminary Results

We consider a dynamic economy with durable and nondurable goods. Some goods have sticky prices and others have flexible prices. The standard New Keynesian model with only nondurables and symmetric price rigidity is a special case of the model. We focus on durable consumption goods rather than productive capital to emphasize that it is durability that is the key issue and not what the good is used for.[9]

3.1 Households

Consumers get utility from both nondurable and durable consumption goods. Goods are indexed by j. C refers to nondurable goods and D refers to durable goods. Thus, a typical durable good is D_{jt} and a typical nondurable good is C_{jt}. N_t is labor supplied at date t. Total utility is time separable and additively separable in labor.

$$U = E\left(\sum_{t=0}^{\infty}\beta^t\left[u\left(C_{1t},C_{2t}...,C_{jt},...D_{1t},D_{2t},...D_{jt}...\right)-v\left(N_t\right)\right]\right)$$

To some extent, the additive separability of labor is important for our results. We will return to this point later.

Let X_{jt} denote net purchases of type j goods at time t. The household's nominal budget constraint is then:

$$\sum_j P_{jt}X_{jt} + M_t \leq W_tN_t + \Pi_t + T_t + \left(1+i_{t-1}\right)S_{t-1} - S_t + M_{t-1},$$

[9] We discuss productive capital briefly later.

Here, Π_t are profits returned to the consumer through dividends, T_t are lump-sum nominal transfers net of taxes, M_t are nominal money balances held at time t, S_t is nominal savings and i_t is the nominal interest rate. For nondurables $C_{jt} = X_{jt}$ while for durable goods:

$$D_{jt} = X_{jt} + D_{jt-1}\left(1-\delta_j\right).$$

We allow for different rates of physical depreciation for different durable goods.

Labor Supply and the Demand for Goods and Services

Taking prices as given, consumers choose X_{jt}, N_t, and S_t to maximize utility. Let λ_t be the marginal utility of an additional dollar of income at time t and let γ_{jt} be the shadow value - the contribution to lifetime utility of an additional unit - of good j. If good j is a nondurable, then the shadow value is simply the current marginal utility of an additional unit: $\gamma_{jt} = MU_{j,t}^C$ where $MU_{j,t}^C$ denotes the marginal utility of nondurable j at time t. If j is a durable, γ_{jt} is the present value of future marginal service flows of the durable, discounted by the subjective rate of time preference and the depreciation rate:

$$\gamma_{jt} = MU_{jt}^D + \beta\left(1-\delta_j\right)MU_{j,t+1}^D + \beta^2\left(1-\delta_j\right)^2 MU_{j,t+2}^D + ... \quad (1)$$

This equation turns out to be a key equation in the model.

The first order condition for the purchase of any good j is:

$$\gamma_{jt} = \lambda_t P_{jt}. \quad (2)$$

The first order condition for the supply of labor (N_t) is $v'\left(N_t\right) = \lambda_t W_t$. Finally, the first order condition for savings (S_t) implies that the nominal interest rate satisfies:

$$\lambda_t = \beta\left(1+i_t\right)E_t\left[\lambda_{t+1}\right]. \quad (3)$$

Combining (2) with the first order condition for labor supply gives a set of conditions (one for each good) that relate employment to the demand for goods and services:

$$v'\left(N_t\right) = \frac{W_t}{P_{jt}}\gamma_{jt}. \quad (4)$$

Equation (4) says the utility cost of an additional unit of labor must be exactly balanced by the benefit of spending W_t extra dollars on any of the goods in the economy.

Money Demand

Money is injected into the economy through lump sum transfers T_t to the agents (T_t can be negative). We do not model the demand for money explicitly. For simplicity we assume that money demand is proportional to nominal purchases:

$$M_t = \sum_j P_{jt} X_{jt} \ .$$

Of course, money demand might also be related to the nominal interest rate (an "LM curve") or other macroeconomic variables, but this is inessential for the basic results. The important feature of money demand is that when the money supply increases, firms have incentives to raise their prices.

3.2 Firms

We treat productive capital as a predetermined fixed factor but we allow labor to flow freely across industries (later we relax both of these assumptions). Firms convert labor input into outputs according to their production functions.

$$X_{jt} = F_j\left(n_{jt}\right)$$

Where n_{jt} is employment in sector j. We allow each firm to have a different production function. We assume that each F_j satisfies $F_j' > 0$ and $F_j'' \leq 0$ so that all production has non-increasing returns to scale in labor. In equilibrium labor supply and labor demand must be equal:

$$\sum_j n_{jt} = N_t \tag{5}$$

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. Because labor is free to flow from one industry to the next, the nominal wage rate W_t will be the same across industries. In our model, labor is the only input to production. Thus, we write the nominal marginal cost in industry j as

$$MC_{jt} = W_t\left[\partial x_{jt} / \partial n_{jt}\right] = W_t\left[MP_{jt}^N\right]^{-1}, \tag{6}$$

where MP_{jt}^N is the marginal product of labor in sector j.

We assume that firms have constant desired markups over marginal costs.[10] This assumption serves to isolate the direct role of sticky prices in generating business cycles. With constant desired markups, any deviation of the markup from its desired level must come from nominal rigidities. Thus, the sticky prices in the final goods markets do all of the work in our model. The desired markup in sector *j* is denoted as μ_j^*.

Firms that are able to change prices freely simply maintain their constant desired markups. For these firms $\mu_{jt} = \mu_j^*$. Firms with sticky prices will endure periods in which their markups deviate from their desired level. In a period of monetary expansion, these firms will have *actual* (or *ex post)* markups that fall below the planned or *ex ante* level.[11]

3.3 Durable Goods and Temporary Shocks

Several results stem directly from the presence of highly durable goods in models with temporary shocks. These results are only approximate in nature and the approximations are best when the durables are very long-lived.

Intertemporal Substitution and Purchases of Durable Goods

In sections 4 and 5, we show that the behavior of sticky price models depends crucially on how durable goods prices are set. The reason that durable goods sectors exert so much influence over these models is that the intertemporal elasticity of substitution for purchases of durable goods is inherently high. The lower the rate of depreciation is, the higher is the intertemporal elasticity of substitution. For durables like housing, with annual rates of depreciation less than five percent, this elasticity is nearly infinite.

To be more specific, we claim that the shadow value (γ) of a long-lived durable is roughly constant when shocks are temporary. Since real effects of money shocks are inherently temporary, γ should be approximately constant following a change in the money supply.

[10] This can be justified with a C.E.S. (Dixit-Stiglitz) preference structure. We use this formulation explicitly for the numerical model in the next section. More generally, firms will desire markups that fluctuate with changes in demand. See Bils [1989] for a discussion of endogenous markups.

[11] We do not need to take a position on the exact form of price stickiness at this point. In the simulations, we use a Calvo specification to generate price rigidity.

To understand this claim, it is useful to return to equation (1), which expresses this shadow value as a discounted sum of marginal utilities:

$$\gamma_{jt} = MU^D_{jt} + \beta\left(1-\delta_j\right)MU^D_{j,t+1} + \beta^2\left(1-\delta_j\right)^2 MU^D_{j,t+2} + \ldots$$

We make two observations: First, the steady state stock-flow ratio is $1/\delta_j$.[12] For a highly durable good, this ratio is high (by definition). Suppose for the moment that the marginal utility terms in (1) depend only on the stock of the durable in question. Because the stock-flow ratio is high, even large changes in purchases will have only minor effects on the total quantity of the durable. Modest fluctuations around the steady state leave the stock of such goods, and thus their shadow value, nearly constant at cyclical frequencies. In this case, γ_{jt} will display minimal cyclical movement.

In general, the marginal utility of a durable depends on both the stock of the durable and on other goods and services. Changes in the production or consumption of other goods could influence the marginal utility terms in (1) and cause γ to change. This brings us to our second observation: γ is a forward-looking variable. The extent to which γ is forward-looking depends on the subjective rate of time preference (β) and on the economic rate of depreciation (δ). Again, because monetary shocks are temporary, only the first several terms in the sum will be affected by interactions with other variables. If β is high and δ is low, the shadow value is dominated by future terms and the change in γ due to a temporary shock is small.

These observations suggest that it is reasonable to treat the shadow values of highly durable goods as roughly constant in response to monetary disturbances and other temporary shocks. For durables with rapid rates of depreciation (computers and vehicles for instance) the approximation is less justifiable.

Relative Prices and Real Interest Rates

The near constancy of the shadow value of highly durable goods has important implications. One implication is that the relative price of one durable to another should remain roughly constant over the business cycle.

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[12] Our model does not have long-run growth. With growth, the stock-flow ratio is 1/(δ+ *growth rate*).

In neoclassical models, consumers choose their spending so that the marginal utility per dollar is equal across commodities. For any two goods *i* and *j*, we have:

$$\frac{\gamma_{j,t}}{P_{j,t}} = \frac{\gamma_{i,t}}{P_{i.t}}.$$

If *i* and *j* are durables then $\gamma_{j,t} \approx \gamma_j$ and $\gamma_{i,t} \approx \gamma_i$ and we can write the price ratio as:

$$\frac{P_{j,t}}{P_{i.t}} = \frac{\gamma_{j,t}}{\gamma_{i,t}} \approx \frac{\gamma_j}{\gamma_i}.$$

Thus, while the relative prices of nondurables may react to monetary policy, for highly durable goods, relative prices will remain constant. Because our model allows workers to flow freely across sectors, constant relative prices imply that cyclical movements in the real product wages ($W_t / P_{j,t}$) in durables sectors must be highly correlated.[13]

Many economists feel that real interest rates are central to the monetary transmission mechanism. In economies with more than one good, one cannot talk about *the* real interest rate without ambiguity. Instead, every commodity has its "own real rate of return" defined by the Fisher equation:

$$1 + r_{j,t} \equiv \left(1 + i_t\right) \frac{P_{j,t}}{P_{j,t+1}} = \frac{1}{\beta} \frac{\gamma_{j,t}}{\gamma_{j,t+1}}, \tag{7}$$

where the second equality comes from the Euler equation (3). In general, these real rates of return can vary across commodities and over time due to variations in the shadow values.

For a long-lived durable, however, the own real rate of return must remain constant in the face of a monetary policy shock. Again this is a consequence of $\gamma_{j,t} \approx \gamma_j$ when *j* is a durable. The near constancy of the shadow value implies that the real interest elasticity of demand for these goods is nearly infinite. Thus, whatever effects monetary policy has on other real interest rates, the real rate of return on durables will not react to monetary policy.

The constant shadow value of durables also has consequences for nondurables. Consider a nondurable (good *i*). Its shadow value is simply its marginal utility:

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[13] While there are distinct real product wages for the nondurables, there is really only one real wage for durable goods. Condition (4) shows that real product wages for durable goods must be procyclical. Although real product wages in many sectors may exhibit either pro- or counter-cyclicality, in our model, only real wages in durables sectors need be procyclical.

$\gamma_{i,t} \approx MU^C_{i,t}$. If the utility function is additively separable in consumption then the marginal utility is only a function of $C_{i,t}: MU^C_{i,t} = u'(C_{i,t})$. Then, if *j* is a long-lived durable, we can write

$$u'(C_{i,t}) \approx \left(\frac{P_{i,t}}{P_{j,t}}\right)\gamma_j .$$

This equation says that, in equilibrium, consumption (and production) of a nondurable is matched by the change in its price relative to any one of the durables. We return to this point later in the numerical simulations.

4. FLEXIBLE DURABLE GOODS PRICES

The focus of the paper is on the role that durable goods play in sticky price models. The facts are clear: real purchases of durables are extremely procyclical. This is especially true for the production of new homes. In addition, the real relative price of durables to nondurables rises following a monetary expansion. Coherent models of the monetary business cycle should be able to reproduce these facts.

In this section we demonstrate that flexible durable goods prices present problems for sticky price models of the business cycle. To make this point starkly, we consider a durable with fully flexible prices. This is an instructive special case because it clearly exposes the problem and the mechanisms at work in the model. We assume the good is sufficiently durable (i.e. its depreciation rate is sufficiently low) that our approximation of a constant shadow value is appropriate.

4.1 THE COMOVEMENT OF DURABLE GOODS PURCHASES

The acyclicality of the shadow price of the durable leads us to drop the time subscript and treat $\gamma_{j,t}$ as roughly constant at some γ_j. For this industry, the labor supply condition is $v'(N_t) \approx \left({W_t}/{P_{jt}}\right)\gamma_j$. Since prices are flexible in this sector, the price of the good is a constant markup over its marginal cost: $P_{j,t} = \mu_j \left(W_t / MP^N_{j,t}\right)$. Combining these expressions (in essence, equating labor supply and labor demand) implies that:

$$v'(N_t) \approx \frac{\gamma_j}{\mu_j} MP^N_{jt} \,. \tag{8}$$

This equation bears directly on the comovement of aggregate employment and production of the durable in question. If aggregate employment rises in response to expansionary monetary policy, 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 (8) must also rise. With γ_j and μ_j time-invariant, the marginal product of labor must rise and employment in the durables sector falls. Thus, employment and output in a long-lived durable industry exhibits negative comovement with aggregate employment and output whenever the durable has a flexible price.

This result is remarkably robust. Aside from the assumption of labor mobility, deriving equation (8) required only that the good was a long-lived durable with flexible prices (i.e. γ_{jt} and μ_{jt} were approximately constant). Among other things, the negative comovement of flexibly priced durables is independent of the demand structure of the other goods, the form of price rigidity in the sticky-price sectors, and the money supply rule. As a result, the ability of a sticky price model to match basic features of the data is severely compromised if long-lived durables have flexible prices.

4.2 Sticky Prices and the Neutrality of Money

The comovement problem concerns the behavior of a single durable goods sector as aggregate employment varied. We can go further if *all* durables had flexible prices. In this case, even if most of the goods in the economy have sticky prices, it is possible for money to be neutral with respect to aggregate output and employment. Like models in which all prices are flexible, the aggregate price level will move one-for-one with changes in the money supply.

Unlike the comovement result, the conditions for aggregate neutrality are more stringent. In addition to assuming that labor is mobile, we assume that the marginal rate of transformation from one good to another is constant. An easy way to ensure a constant marginal rate of transformation is to assume that production is linear in each sector so that $X_{j,t} = An_{j,t}$ for all j. Now equation (8) implies:

$$v'\left(N_t\right) \approx \frac{\gamma_j}{\mu_j} MP_{j,t}^N = \frac{\gamma_j}{\mu_j} A .$$

Since the marginal product of labor is constant, we have one equation in the one *aggregate* variable N_t. Following a money shock, the level of employment that solves this equation is the steady state level of employment. Thus, aggregate employment will not vary over the cycle and money will be neutral. This is approximately true *regardless* of how much price rigidity there is in the nondurables sectors and regardless of the ratio of nondurables to durables.

A constant marginal rate of transformation can also be achieved with constant returns to scale production functions and mobile factors. To see this, suppose that production requires both labor and capital. The aggregate capital stock (K) is fixed but capital can flow freely across sectors. Let k_{jt} denote the capital in sector j.

Assume that production in each sector has the same constant returns to scale production function:

$$X_{j,t} = F\left(k_{j,t}, n_{j,t}\right).$$

Because factors flow freely across industries, nominal wages and rental prices will be equal in each sector. Since the production function is homogeneous of degree one, cost minimization implies that the capital-to-labor ratios will equalize across industries regardless of which ones have sticky prices and which ones have flexible prices. Industries that increase production do so by hiring capital and labor in the same proportions as other industries. This implies:

$$\frac{k_{it}}{n_{it}} = \frac{k_{jt}}{n_{jt}} = \frac{K}{N_t}.$$

The marginal product of labor in any sector depends only on the capital-to-labor ratio:

$$MP_{jt}^N \equiv \frac{\partial F\left(k_{jt}, n_{jt}\right)}{\partial n_{jt}} = F_N\left(1, \frac{n_{jt}}{k_{jt}}\right) = \varphi\left(\frac{k_{jt}}{n_{jt}}\right) = \varphi\left(\frac{K}{N_t}\right).$$

Equating labor supply and labor demand in the durable goods sector gives

$$v'\left(N_t\right) = \frac{\gamma}{\mu} MP_{jt}^N = \frac{\gamma}{\mu} \varphi\left(\frac{K}{N_t}\right). \tag{9}$$

This is one equation in aggregate employment (N_t), and again employment is approximately constant and money is neutral.[14]

4.3 Immobile Labor and "Factor Attachment"

Many researchers emphasize the important role that factor attachment can play in sticky price models (see for instance Ball and Romer [1990], Kimball [1995] and Woodford [2003]). Because it insulates one industry from another, factor attachment slows down price adjustment by tempering the increase in costs for firms that reset their prices.

The model we presented above does not have factor attachment. We made exactly the opposite assumption: labor (and capital) were free to flow from one industry to another. If aggregate employment rose then costs rose in all industries. To allow for factor attachment, we modify the model by changing the utility function.

$$U = E\left[\sum_{t=0}^{\infty}\beta^t\left\{u\left(C_{1t},C_{2t}...,C_{jt},...D_{1t},D_{2t},...D_{jt}...\right)-\sum\nolimits_j v_j\left(N_{jt}\right)\right\}\right]$$

This utility function embodies an extreme form of factor attachment: each industry has its own labor supply pool and there is no substitution of labor at all across industries.

With factor attachment, pressure on labor markets in sticky price sectors has no effect on the supply of labor in flexible price sectors. The labor market clearing condition in a durable sector with flexible prices is now:

$$v_j'\left(N_{jt}\right)=w_{jt}\frac{\gamma_{jt}}{P_{jt}}=\frac{MP_j^N\left(N_{jt}\right)}{\mu_j}\gamma_j \tag{10}$$

This equation pins down N_{jt}. When factors are totally bound to specific sectors, employment in (flexibly priced) durable goods sectors will not vary with the business cycle. Thus, although factor attachment helps to alleviate comovement problems, it cannot solve them. By itself, factor attachment can, at most, render these industries acyclical.

[14] If productive capital is highly durable, we do not need to assume that it is fixed. Like all long-lived durables, the aggregate capital stock will not move much over the cycle. In this case, we can safely treat K_t as approximately fixed over business cycle horizons.

4.4 Discussion

What is the underlying mechanism generating the comovement and neutrality results? Following a monetary expansion, sticky price firms continue to meet demand at fixed prices. In terms of utility, the marginal cost of an additional unit of good *j* is $v'(N_t)/MP_{jt}^N$. The incipient increase in output in sticky price sectors increases the demand for labor, which, in turn raises $v'(N_t)$ and raises marginal costs. In a more general model, as the economy expands, pressure on all input markets (labor markets, markets for fuel and raw materials, etc.) rises.

In the face of rising marginal costs, flexible price firms maintain their markups by raising prices. Is there a sufficient shift in demand for the flexibly priced product to more than offset the contractionary effect of the price increase? For a sufficiently long-lived durable good, the answer is no. The demand schedule for such a good does not shift very much because the shadow value of the durable is largely invariant to temporary shocks. Since the rise in the real price of durables is temporary, consumers intertemporally substitute and postpone purchases.

In the data, production of durables (housing in particular) seems to respond strongly to monetary policy. Because monetary shocks in sticky price models do not shift the demand curves for these goods, models based on nominal rigidities must attribute some price rigidity directly to durable goods sectors.

5. Simulating the Model

While the results in the previous section are robust to a variety of specifications, they apply only when durable goods have perfectly flexible prices. To see what happens when durables have rigid prices requires a numerical analysis. For numerical solutions, we must take a stand on the precise functional forms for the utility, and production functions, and for the precise nature of price rigidity.

To keep matters simple, the numerical model has only two sectors: a durable goods sector and a nondurable goods sector. The precise utility function is:

$$\sum_{t=0}^{\infty}\beta^{t}\left\{\frac{1}{1-\frac{1}{\sigma}}\left[\left(\psi_{c}C_{t}^{1-\frac{1}{\rho}}+\psi_{d}D_{t}^{1-\frac{1}{\rho}}\right)^{\frac{\rho}{1-\rho}}\right]^{1-\frac{1}{\sigma}}-\phi\frac{N_{t}^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}}\right\} \tag{11}$$

The CES aggregator has the (standard) properties that as the elasticity of substitution $\rho \to\infty$, C and D become perfect substitutes, as $\rho \to 1$ the Utility function is the generalized Cobb-Douglas function $C_t^{\psi_c}D_t^{\psi_d}$, and as $\rho \to 0$, the utility function becomes Leontief so that C_t and D_t are perfect complements. σ is the intertemporal elasticity of substitution, and η is the Frisch labor supply elasticity (ϕ is a scaling parameter).

For this model, the consumer's demand and supply functions can be summarized by two equations: an Euler equation and a labor supply equation.

$$U_{t}^{\frac{1}{\rho}-\frac{1}{\sigma}}C_{t}^{-\frac{1}{\rho}}\frac{P_{x,t}}{P_{c,t}}=U_{t}^{\frac{1}{\rho}-\frac{1}{\sigma}}\frac{\psi_{d}}{\psi_{c}}D_{t}^{-\frac{1}{\rho}}+\beta\left(1-\delta\right)E_{t}\left[U_{t+1}^{\frac{1}{\rho}-\frac{1}{\sigma}}C_{t+1}^{-\frac{1}{\rho}}\frac{P_{x,t+1}}{P_{c,t+1}}\right], \tag{12}$$

$$\phi N_{t}^{\frac{1}{\eta}}=\psi_{c}\frac{W_{t}}{P_{c,t}}U_{t}^{\frac{1}{\rho}-\frac{1}{\sigma}}C_{t}^{-\frac{1}{\rho}}. \tag{13}$$

Where $P_{x,t}$ and $P_{c,t}$ are the nominal prices of the durable and the nondurable and where $U_{t}=\left(\psi_{c}C_{t}^{1-\frac{1}{\rho}}+\psi_{d}D_{t}^{1-\frac{1}{\rho}}\right)^{\frac{\rho}{1-\rho}}$.

Final goods in each sector are produced from intermediate goods according to a Dixit-Stiglitz aggregator:

$$X_{j,t}=\left[\int_{0}^{1}x_{j,t}\left(s\right)^{\frac{\varepsilon-1}{\varepsilon}}ds\right]^{\frac{\varepsilon}{\varepsilon-1}},\ \varepsilon>1 \tag{14}$$

for $j = C, D$. Final goods producers are competitive while each intermediate goods producer enjoys a local monopoly. Free entry into the production of final goods implies:

$$P_{j,t}=\left[\int_{0}^{1}p_{j,t}\left(s\right)^{1-\varepsilon}ds\right]^{\frac{1}{1-\varepsilon}} \tag{15}$$

so that the demand for any one intermediate good (s) satisfies:

$$x_{j,t}\left(s\right)=X_{j,t}\left(\frac{p_{j,t}\left(s\right)}{P_{j,t}}\right)^{-\varepsilon} \tag{16}$$

for $j = C, D$. ε is the price elasticity of demand. Because the elasticity of demand is constant in this setting, it is optimal to maintain a constant markup over nominal marginal costs. This markup is $\mu = \frac{\varepsilon}{\varepsilon - 1} > 1$. We assume that the production of intermediate goods in each industry is linear in employment so that $X_{j,t}(s) = An_{j,t}(s)$.[15]

We use a Calvo price setting mechanism to motivate sluggish price adjustment. θ_j is the probability that a firm in industry $j = C, D$ cannot reset its price in any one period. Thus, in each period, $1-\theta_j$ firms reset their prices while θ_j firms have prices that are stuck at their levels from the previous period. When they can, firms set prices so the expected average markup over the foreseeable future equals its desired markup. The optimal reset price is a weighted average of current and future marginal costs.

If $\tilde{v}$ is the percent deviation of a variable v from its steady state value, then, to a first order approximation, the optimal reset price ($P^*_{j,t}$) satisfies:

$$\tilde{P}^*_{j,t} \approx (1-\theta_{j,t}\beta)\tilde{W}_t + \theta_{j,t}\beta E_t\left[\tilde{P}^*_{j,t+1}\right] \tag{17}$$

(Note, if there were no price rigidity, $\theta = 0$ and prices would be proportional to nominal marginal cost). Using (15) we can approximate the final goods prices as:

$$\tilde{P}_{j,t} = \theta_j \tilde{P}_{j,t-1} + (1-\theta_j)\tilde{P}^*_{j,t} \tag{18}$$

Because price adjustment under the Calvo mechanism is random, the aggregate production functions are:

$$X_{j,t} = AN_{j,t} \tag{19}$$

where $N_{j,t} = \int n_{j,t}(s)ds$ for $j = C, D$.

Finally, we assume the money supply follows a random walk:

$$M_t = M_{t-1} + \xi_t, \tag{20}$$

where ξ_t is a mean zero *i.i.d.* disturbance. The model is solved by log-linear approximation in the neighborhood of the non-stochastic steady state.

Parameter Values:

We choose parameter values that are typical in the business cycle literature. Table 2 summarizes our parameter settings. We set the Frisch labor supply elasticity (η) to 1. The intertemporal elasticity of substitution (σ) is 0.2 and the subjective time discount

[15] Though somewhat unorthodox, this specification illustrates the "neutrality result" from section 4.2.

factor (β) is .98, which implies a real interest rate of 2% per year. We assume that $\rho = 1$ so that the within-period utility function is $C_t^{\psi_c} D_t^{\psi_d}$. ε is set to give a desired markup of 10%. We set the annual depreciation rate to 10%.[16] ψ_c and ψ_d are set to give a steady state ratio of nondurables to GDP of 0.75.

We consider various degrees of price rigidity. As a benchmark, we assume that sticky-price sectors have Calvo parameters that imply a six-month half-life of exogenous price rigidity (i.e. for any firm, there is a 50% chance that it will be able to reset its price within half a year). For models with staggered price setting, this corresponds to one year of fixed prices. A six-month half-life requires an annual continuous time Calvo parameter of $2\ln(2) = 1.3863$, so that on average firms reset prices 1.4 times per year.[17]

5.1 Symmetric Price Rigidity

We begin by considering symmetric price rigidity. That is, we assume that prices are equally sticky across sectors. Because production is linear, the model has a constant marginal rate of transformation across sectors. This is a natural place to start since many sticky price models have only one good and thus implicitly make both of these assumptions.

<u>Nondurable Goods</u>

Many New Keynesian models omit durable goods entirely.[18] Because models with only nondurables are prevalent in the literature, we consider this special case first.

Suppose the economy produces a single nondurable good. Thus $C_t = X_t = AN_t$ and $M = P_t C_t = P_t A N_t$. Figure 2.A (the top row of panels) shows the model's reaction to a permanent unanticipated one percent increase in the money supply.

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[16] Buildings have depreciation rates that are closer to 3%, vehicles and transportation equipment have depreciation rates that are closer to 15%. We use 10% because it is a standard value in the business cycle literature. See Hulten and Wykof [1979] and [1981] or Fraumeni [1997] for more details.

[17] This is a considerable amount of price rigidity. Bils and Klenow [2002] find that, on average, prices of many consumer goods change once every four months, which suggests a Calvo parameter closer to 3.

[18] Prominent examples include Clarida, Gali and Gertler [1999], Rotemberg and Woodford [1997], and Woodford [2003]. Dotsey, King and Wolman [1999] include capital as a fixed factor. Kimball [1995], and Chari, Kehoe and McGrattan [2000] include capital as a variable factor of production.

The first panel plots the change in production. Prices are sticky in the short run. Thus, immediately after the shock, production and consumption rise by one percent. In the first quarter following the shock, GDP is above trend by 0.66 percent. The second panel shows the evolution of prices. Over time, prices adjust and production, employment and consumption all return to their steady state levels.

The last panel shows the reaction of interest rates. Since there is only one good, there is a single real interest rate. The real rate of return is related to consumption via the Euler equation:

$$1+r_t = \frac{u'(C_t)}{\beta E_t\left[u'(C_{t+1})\right]}$$

Since consumption is falling, $u'(C_t) < \beta E_t\left[u'(C_{t+1})\right]$, and the real interest rate is below its steady state level. As prices adjust, the real interest rate returns to its steady state level.

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. Figure 2.B (the lower row of panels) shows the equilibrium reaction to the same money shock.

The first panel shows total GDP, total nondurable consumption and the total production of the durable good. As before, output and employment increase in the short run and then slowly fall back to their steady state levels. In the first quarter following the shock, total output rises by 0.82%.[19] Production of the durable increases by 3.2% in the first quarter. Unlike the previous case however, production of the nondurable remains almost constant; in the quarter after the shock, production rises by 0.02%. In essence, the production of new durable goods accounts for the entire increase in GDP.

[19] The plot makes it look like output rises by 1% because it is plotting the first 100th of a year rather than the first quarter. Note that because output is linear in employment, the employment response is also 0.82%.

Because prices are equally sticky, and because the marginal rate of transformation is constant, the relative price of durables to nondurables does not change. Thus, $u'(C_t) = \gamma_{D,t}$. If the stock-flow distinction for the durable is strong, then $\gamma_{D,t} \approx \gamma_D$ and $u'(C_t)$ and thus C_t are approximately constant. This relates to a result from Section 3: nondurable consumption is determined by the equilibrium behavior of the relative price P^x/P^c. With symmetric price rigidity and a constant marginal rate of transformation, this relative price is constant so nondurable consumption doesn't react to monetary disturbances. This is true even though their prices are very sticky. That there are nondurables with sticky prices that don't react to monetary policy is completely consistent with theories of nominal rigidity.

The last panel plots the response of interest rates. In Section 3, we concluded that the own real rates of return on durables were constant. In the simulation, we see that neither the own real rate of return on durables nor the own real rate on nondurables reacts to the shock. The real interest rate for nondurables is unchanged because nondurable consumption itself doesn't move. Since the real rates of return are constant, nominal interest rates rise to reflect the increased expected inflation.

5.2 Asymmetric Price Rigidity

We now consider what happens when some goods have flexible prices. We begin with flexible nondurable goods prices and sticky durable goods prices. Because the nondurables have flexible prices and are seventy five percent of GDP one might think that the response of the model to monetary shocks would be roughly one quarter of the response when all prices were sticky. As we will see, this is not the case.

Sticky Durables Prices and Flexible Nondurables Prices

Suppose that the nondurable goods have fully flexible prices while the durables have sticky prices. Recall that the durables industry is the smaller industry; only 25% of GDP has sticky prices. Figure 3.A (the top row) shows the response to the monetary shock.

Even though durables (the sticky price goods) are only one quarter of GDP, output rises by 0.46% in the first quarter. This is more than half of the increase in GDP when all prices were sticky. There is a modest comovement problem. Nondurable consumption falls by 0.13% in the first quarter while durable goods production rises by 2.21 percent. This is not unlike the behavior we see in the data.

Because prices differ across sectors, there is a difference between the aggregate price level and the price of either the durable or the nondurable alone. We define the aggregate price level as $\overline{P}_t \equiv P_{C,t}C + P_{X,t}X$ where C and X are steady state levels of nondurable and durable goods production. In the figure, the aggregate price level (the dark line) jumps after the shock and then slowly converges to the higher level. The figure also shows that *both* individual prices adjust slowly. Even though the price of the nondurable is completely flexible it behaves in a manner similar to a sticky price good.

Like the model with symmetric price rigidity, real interest rates show almost no change when nondurables have flexible prices and again, the nominal interest rate rises slightly due to expected inflation.

So, even when durables are only a small fraction of total GDP, when their prices are sticky, the model behaves much like a model in which all prices are sticky. A comparison of Figure 3.A with Figure 2.B shows that the model can be deprived of seventy five percent of its price rigidity and still retain the basic response to monetary shocks: After a monetary shock, prices adjust slowly and interest rates are moderately affected; GDP and employment on the other hand, react strongly to the shock.

Flexible Durables Prices and Sticky Nondurables Prices

Now consider the opposite case in which durables have flexible prices while nondurables have sticky prices. Since the durables have flexible prices and because the marginal rate of transformation across sectors is constant, the analysis in Section 4 applies: We should observe a pronounced comovement problem and a very minor change in total production. Figure 3.B shows the response of the model.

The simulation confirms the approximation result: even though the production of nondurables accounts for 75% of GDP, output barely changes after the money shock. In the first quarter after the shock, output – and thus aggregate employment – falls by a very small amount (0.02%). Even though most prices are sticky, money has essentially no effect on employment and output. The source of this neutrality is the negative comovement in the two sectors. Consumption rises by 0.78% and production of durables falls by 2.44% in the first quarter. In the aggregate, these exactly offset and total production is unchanged.

The price of nondurables rises slowly while the price of durables overshoots in the short run. The aggregate price level jumps by exactly 1% immediately following the monetary shock.

Notice that both the nominal interest rate and the real interest rate for nondurable consumption fall after the monetary expansion. Even though durables are perceived as "interest sensitive" components of aggregate demand, low interest rates do not increase demand for these goods enough to counteract the increased cost of production.

5.3 Modifications and Sensitivity Analysis

Durables play an important role in the numerical model. When all prices are sticky, the presence of durable goods implies that neither real interest rates nor the production of nondurables reacts to monetary policy. The model behaves in much the same way provided the durables have sticky prices; even if they represent a larger share of production, the rigidity or flexibility of the nondurables had very little bearing on the reaction of the model to monetary shocks. On the other hand, if the durables have flexible prices, output and employment don't react and the aggregate price level is always proportional to the money supply. This awkward behavior is unaffected by price rigidity in the nondurables sector.

Here we consider some modifications to the model. Among other things, we ask whether the results depend on complete price flexibility or whether they survive when prices are only moderately flexible.

Relative Price Flexibility

The analysis above assumed that the flexible price sector had *completely* flexible prices. Here we consider mixed cases in which both prices are sticky but one is relatively more flexible than the other. These experiments show that the preceding analysis is not a knife-edge case but rather continues to hold when prices are highly (though perhaps not fully) flexible.

Figure 4 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 4.A) considers variations in the Calvo parameter for the nondurable goods sector (θ_c). The Calvo parameter for the durables (θ_x) is held constant at 1.3863. θ_c ranges from 1 (one price change per year on average) to 24 (two price changes each month).

It is surprising just how little this parameter influences the model over this range. While it is clear that employment and production respond more when nondurables have sticky prices, the basic character of the reaction (of GDP, consumption and durables production) is the same for the different settings. 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 4.B) considers variations in the Calvo parameter for the durable goods sector. Unlike the price rigidity for nondurable goods, changes in the price rigidity of durable goods have drastic effects on the equilibrium. When $\theta_x = 4$, the model reacts in a conventional way. In contrast, when durable goods prices are reset once every month ($\theta_x = 12$), the equilibrium response of total production (and aggregate employment) to the money shock is essentially gone after one quarter. Quarterly data from this model would suggest that production was white noise. High values of θ_x also generate negative comovement between the production of durables and nondurables.

<u>Changes in the Share of Sticky Price Goods and in the Depreciation Rate</u>

In Figure 5 we consider two other sensitivity checks. Figure 5.A plots the percent change in GDP in the year following the monetary 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 (the solid line) from the model with sticky nondurables prices (the dashed line).

In each case, as the fraction of sticky price goods 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 fall in the output response is much 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 consists of durables with sticky prices than when 90% of GDP consists of nondurables with sticky prices.

Figure 5.B considers variation in the depreciation rate for the durable. Again, the two lines distinguish the model with sticky durable goods prices from the model with sticky nondurable goods prices. The horizontal axis represents the degree of durability. Moving to the right is an increase in durability (indicated by a lower depreciation rate). As in the upper panel, the vertical axis represents the increase in production in the year after the shock.

When the durable prices are sticky, output responds more when the depreciation rate is lower. When the depreciation rate is low, workers can accumulate the durable without substantial reductions in its shadow value. In contrast, when the good is less durable, increases in production imply that the marginal utility of the good drops substantially. Workers offset this effect, to some extent, by working less. As we would expect, when durables have flexible prices, increases in durability imply that the stock-flow distinction is sharper. Thus our neutrality approximation works quite well. If the depreciation rate is .03 per year (which is comparable to the depreciation rate for houses), employment increases by less that 0.02 percent in the year following the shock.

<u>"Demand" Complementarities.</u>

When sticky price sectors expand after a money shock, positive spillovers increase demand for other goods even if their prices are flexible. Because money shocks are temporary, however, complementarities have only a limited effect on the shadow value of durables. Because most of the benefits of acquiring a long-lived durable come in the long run, spillover effects from a temporary economic disturbance will have only a small influence on the shadow value of the good. On the other hand, complementarities can have important effects on the shadow value of nondurables. Specifically, such complementarities tie consumption of nondurables to the *stock* of durables. If the stock of the durable does not change much (due to a high stock-flow ratio), then strong demand complementarities reduce the incentive to produce the nondurable. In the limit, the production of nondurables should not react to the shock.

Figures 6.A and 6.B show the reaction of output, consumption and the production of durables as we vary the degree of complementarity between the nondurable and the durable. Complementarity between C_t and D_t is governed by ρ. As ρ approaches 0 the goods become perfect complements. We consider $\rho = 1$, 0.5, 0.1, 0.05, and 0.01.

Again we focus on asymmetric price rigidity. The top row (6.A) assumes that the nondurables have flexible prices while the bottom row (6.B) assumes that durables have flexible prices. In each case, the production of nondurables gets smaller and smaller as complementary increases. When the nondurable had flexible prices (top row), the original change in production was small to begin with. As a result, the increased complementarity has little effect on the equilibrium.

When the durable has flexible prices, the increased complementarity suppresses the incentive to consume more of the nondurable. Output is still approximately neutral (the neutrality result does not rely on the utility function). Since neither Y nor C changes as complementarity becomes complete, in the limit there is no change in the production of durables either. When durables have flexible prices, complementarities between durables and nondurables cause the aggregate neutrality of money to spread to a sector by sector neutrality of money.[20]

<u>Sticky Wages and Input Prices.</u>

When inputs into production have sticky prices, the price of the final good will endogenously inherit some nominal rigidity. This may be why production of certain durables (and nondurables) reacts to monetary policy even though their prices seem flexible. Mathematically, wage rigidity invalidates equation (4). Workers are off their labor supply curves and thus do not equate the marginal disutility of work with the marginal benefit of working.

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[20] This discussion focused on "demand complementarities" by which we mean spillover effects from consumption of one good to another. "Productive complementarities" behave differently. Because they reduce costs of production, a complementarity between the production of nondurables with the production of durables would reduce the tendency for negative comovement of flexibly priced durables.

Here we modify our two-sector model to allow for sticky wages. We follow Erceg, Henderson and Levin [2000] by modeling wage rigidity as a third Calvo process. Effective labor, L_t, is an aggregate of labor "types":

$$L_t = \left[\int_0^1 l_{it}^{\frac{\xi-1}{\xi}} di \right]^{\frac{\xi}{\xi-1}} \tag{21}$$

If firms hire L_t units of effective labor then the demand for any individual labor type is:

$$l_{it} = L_t \left(\frac{w_{it}}{W_t} \right)^{-\xi} \tag{22}$$

Wages for each worker type are set by unions. Unions maximize the utility of the household taking aggregate demand as given. The aggregate wage is:

$$W_t = \left[\int_0^1 w_{it}^{1-\xi} di \right]^{\frac{1}{1-\xi}} \tag{23}$$

Let θ_w be the probability that a union cannot reset its wage in a given period. To a first order approximation, the wages obey:

$$\tilde{w}_t^* = (1-\theta_w\beta)\left[\tilde{P}_t^c + \frac{1}{\eta}\tilde{N}_t - \left(\frac{1}{\rho} - \frac{1}{\sigma} \right)\tilde{U}_t + \frac{1}{\rho}\tilde{C}_t \right] + \theta_w \beta E_t \left[\tilde{w}_{t+1}^* \right] \tag{24}$$

$$\tilde{W}_t = \theta_w \tilde{W}_{t-1} + (1-\theta_w)\tilde{w}_t^* \tag{25}$$

W_t is the aggregate nominal wage rate and w_t^* is the optimal "reset wage".

Figure 7.A shows how the model reacts to a monetary expansion when durables prices are sticky but nondurables prices are flexible. We consider different degrees of wage rigidity. θ_w ranges from 1, which implies that wages are reset on average once per year, to $\theta_w = \infty$ which corresponds to completely flexible wages. Figure 7.B considers the same experiment under the assumption that durables have flexible prices while nondurables are rigid.

The equilibrium responses look similar to the impulse responses in Figures 4.A and 4.B (the differences between them are largely due to differences in the amount of wage and price rigidity we considered). As in Figure 4, additional wage rigidity does not change the equilibrium much when durable goods prices are sticky – it plays a much more important role when durables have flexible prices.

We have also included a plot of the aggregate real wage in the last panel. The aggregate real wage is defined as $W_t/\overline{P}_t$ where $\overline{P}_t$ is the aggregate price level. Not surprisingly, as wages become more and more rigid, the aggregate real wage becomes less and less procyclical.

While they are not necessary when durable goods prices are sticky, nominal wages may play an important role in generating price rigidity for durable goods whose prices would be flexible otherwise. Other forms of sticky intermediate goods prices will function much the same way.

7. Conclusion

Durable goods feature prominently in discussions of monetary policy. In the data, they appear to be among the sectors that respond most to changes in monetary policy. In addition, because durables are perceived as highly interest sensitive items, they also have a central position in the theory of the monetary transmission mechanism. It is therefore somewhat surprising that durables have received so little attention in sticky price models of the business cycle. While sticky-price models have assumed a leading role in monetary business cycle theory, much of our understanding of these models comes from models without durables.

In this paper we examine the consequences that stem from including durable goods in otherwise conventional sticky price models. We show that the behavior of sticky price models depends heavily on whether durable goods are present and whether these 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 very robust and can be so strong as to dominate the aggregate behavior of the model.

The possibility that some long-lived durables have relatively flexible prices is not entirely academic. This is especially true given the lack of direct empirical evidence of price rigidity of such goods. One could argue for instance that housing construction is a flexible price sector of the sort analyzed in this paper. There is no question that residential housing is very durable; the stock-flow ratio is roughly 55 to 1.[21] In the data the price of new houses falls relative to other prices after a monetary contraction. Table 2 shows that unlike the CPI, for which inflation is positively serially correlated, inflation in the median (and average) price of new houses displays negative serial correlation. This suggests that these prices jump and indeed tend to overshoot. This is inconsistent with incomplete (partial) nominal adjustment, which implies that prices should undershoot. Therefore, the overshooting suggests that house prices may be quite flexible. New construction also plays an important part in the business cycle. In 2000, residential investment accounted for 412 billion dollars – roughly 4% of GDP. Fluctuations in residential investment account for more than 18% of the fluctuations in GDP.

There are also conceptual reasons to believe that certain durables have flexible prices. Some durables (like housing) are relatively expensive on a per-unit basis. If implicit or explicit menu costs have important fixed components, there is more incentive to negotiate on the price of these goods. Moreover, some durables are priced for the first time when they are sold.[22] Others require considerable customization, which is often accompanied by price negotiations.[23]

Sticky price models require additional features if they are to accommodate durables with flexible prices and still match the central features of the data. To this end, wage rigidity, factor attachments and borrowing constraints may be necessary features of New Keynesian theories.

[21] There are roughly 72 million owner occupied houses in the U.S. In 2000, there were 1.3 million housing starts of 1-4 unit dwellings.

[22] For sticky prices to affect the quantity produced, prices must be set prior to production. House prices are often negotiated and are likely to be determined when they are sold.

[23] Zbaracki, *et al*. [2002] present evidence obtained "in the field" on negotiations between large business customers and sales representatives of a large supplier of industrial durables. They show that salesmen have considerable leeway to offer deals to customers who express dissatisfaction with the list price.

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Inflation	k^{th} Order Autocorrelation:											
Lag *k*:	1	2	3	4	5	6	7	8	9	10	11	12
CPI	0.73	0.69	0.71	0.60	0.55	0.51	0.45	0.35	0.37	0.35	0.31	0.30
Nondurables CPI	0.41	0.46	0.46	0.32	0.28	0.26	0.23	0.08	0.14	0.09	0.08	0.05
Durables CPI	0.66	0.58	0.64	0.49	0.46	0.50	0.41	0.39	0.45	0.35	0.33	0.31
Automobiles CPI	0.26	0.19	0.14	0.25	0.31	0.14	0.15	0.17	0.21	0.20	0.11	0.04
Avg House Price	-0.37	0.21	-0.08	0.04	0.12	0.02	0.02	0.00	0.08	0.05	0.01	-0.06
Med House Price	-0.37	0.09	0.06	0.05	-0.01	0.01	0.05	-0.04	0.02	0.06	-0.07	0.00

TABLE 1: AUTOCORRELATION OF INFLATION FOR VARIOUS PRICES

Figure 1.A: Durable and Nondurable Production Following a Romer Date

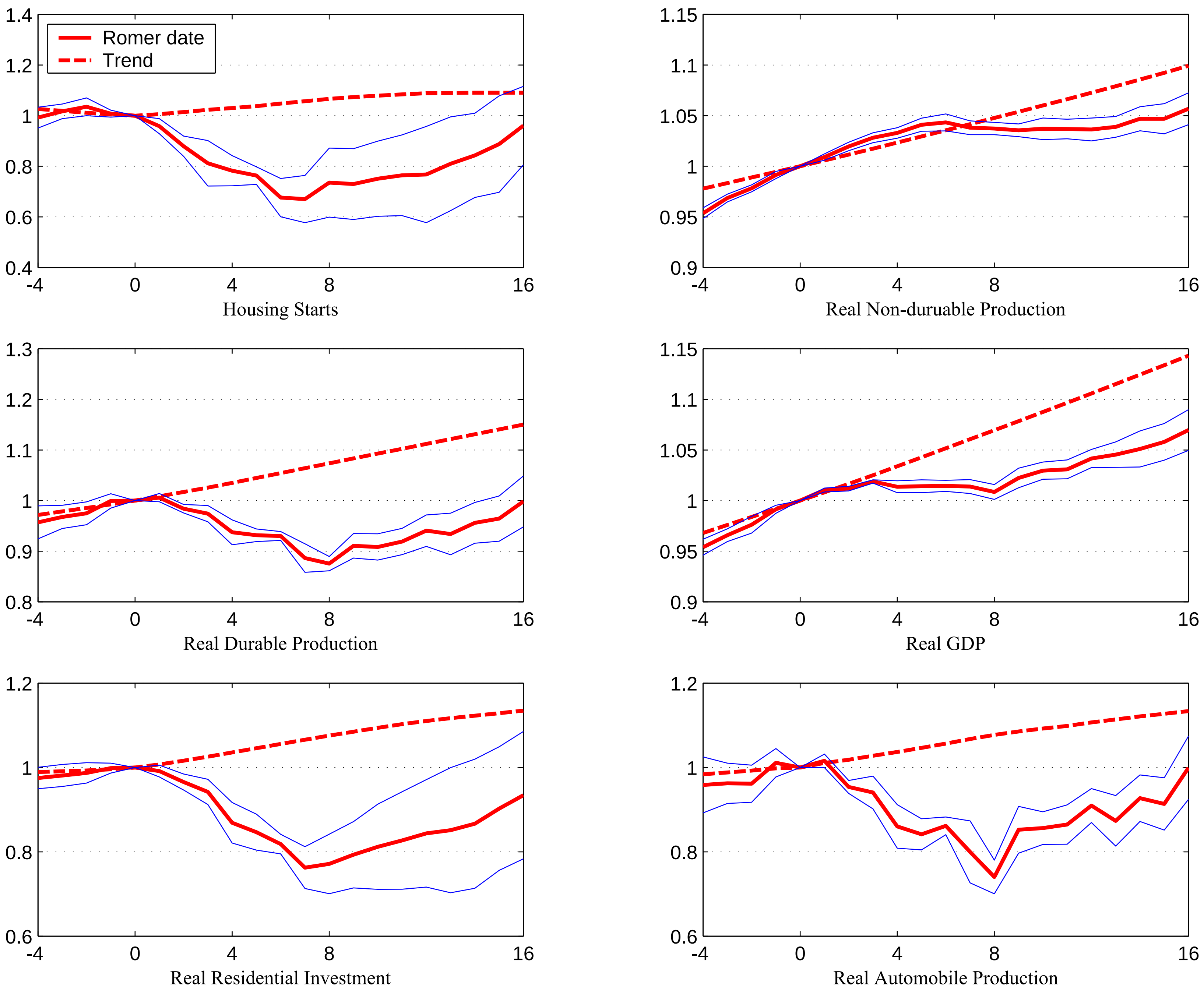

Figure 1.B: Relative Prices Following a Romer Date

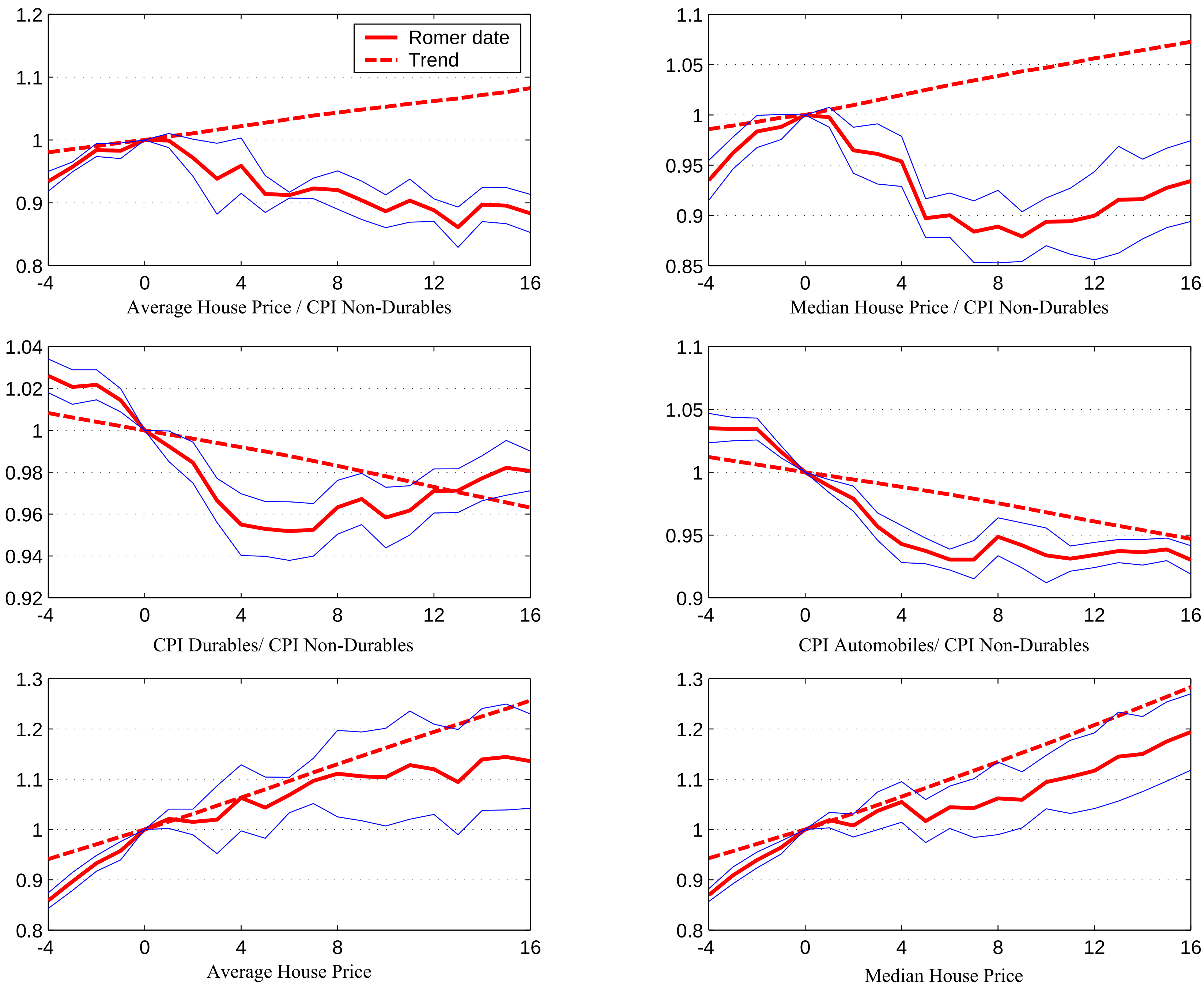

Figure 2: Symmetric Price Rigidity

Figure 2.A: Non-durable Goods Only

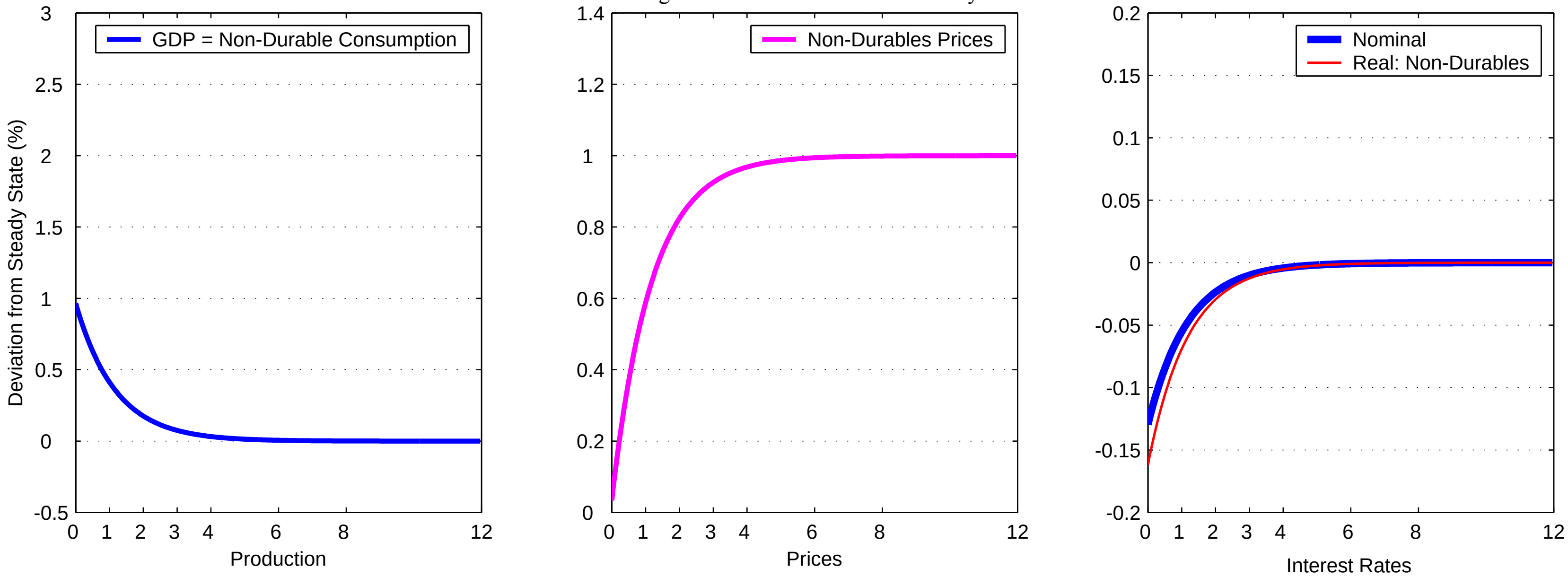

Figure 2.B: Durable and Non-durable Goods

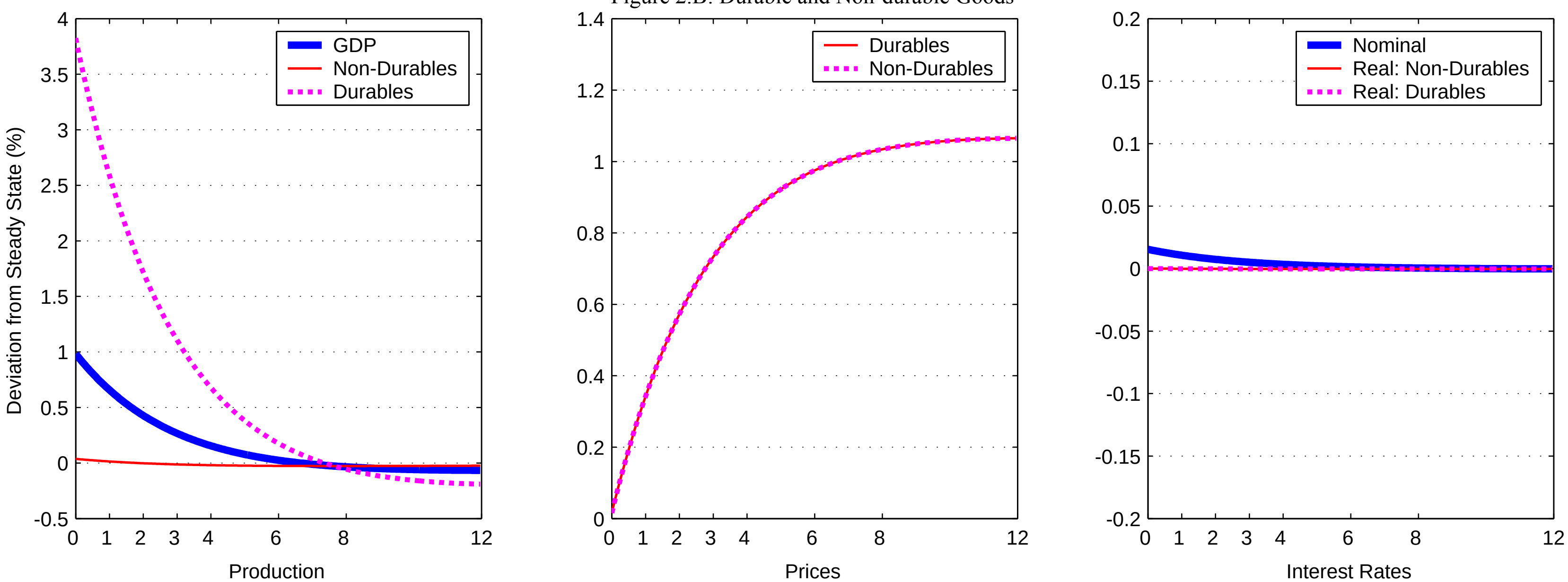

Figure 3: Asymmetric Price Rigidity in Models with Durable Goods

Figure 3.A: Sticky Durables Prices, Flexible Non-durables Prices

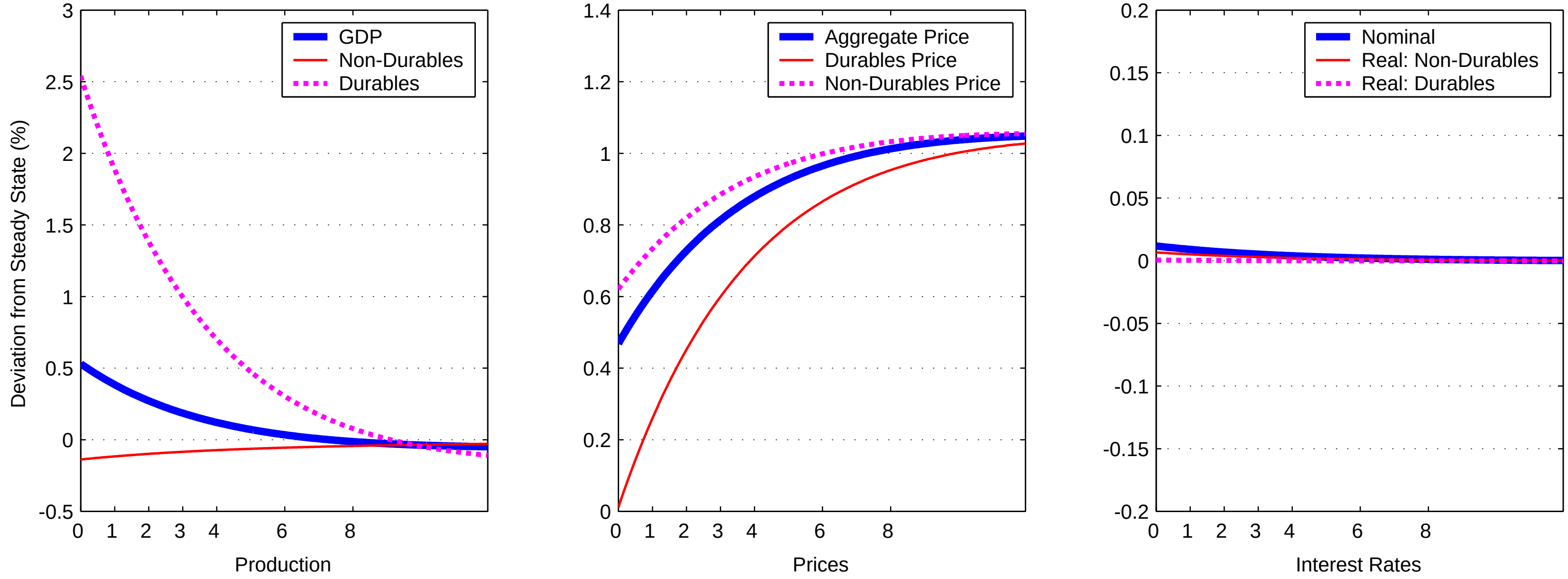

Figure 3.B: Flexible Durables Prices, Sticky Non-durables Prices

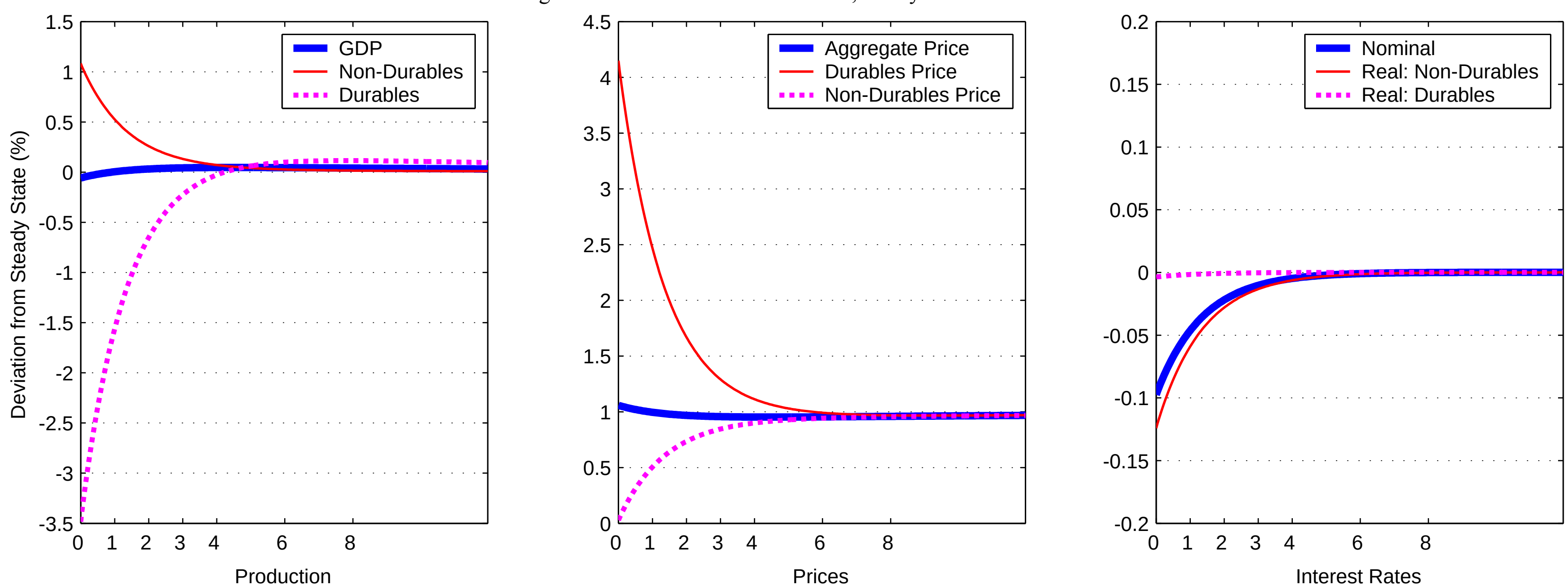

Figure 4: Partially Sticky Prices and Durable Goods

Figure 4.A: Changing the Nominal Rigidity for Non-durables

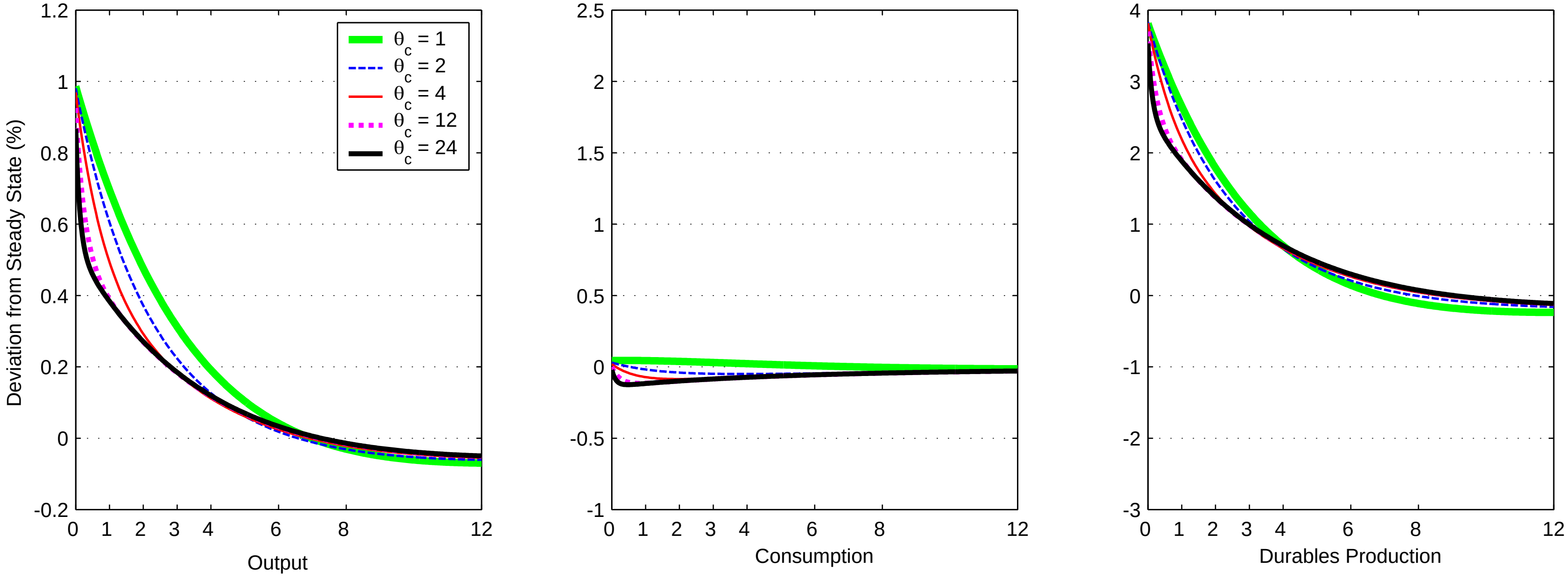

Figure 4.B: Changing the Nominal Rigidity for Durables

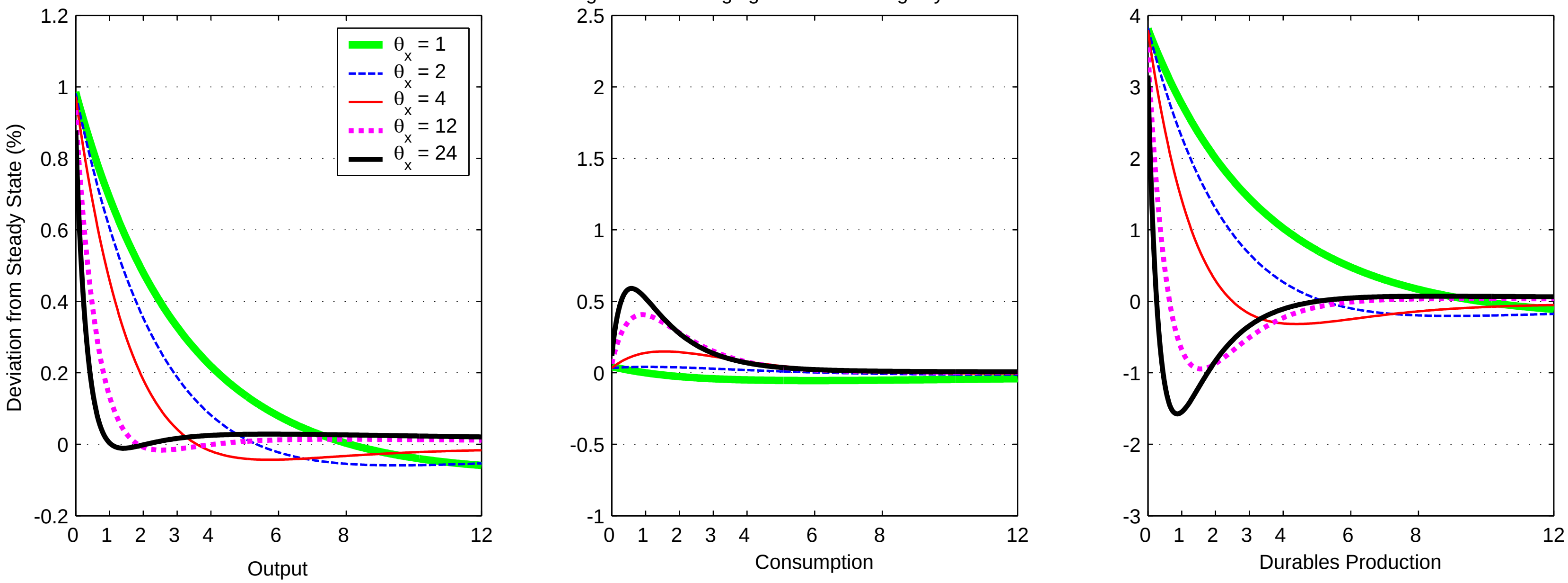

Figure 5: The Share of Sticky Prices in Output and the Degree of Durability

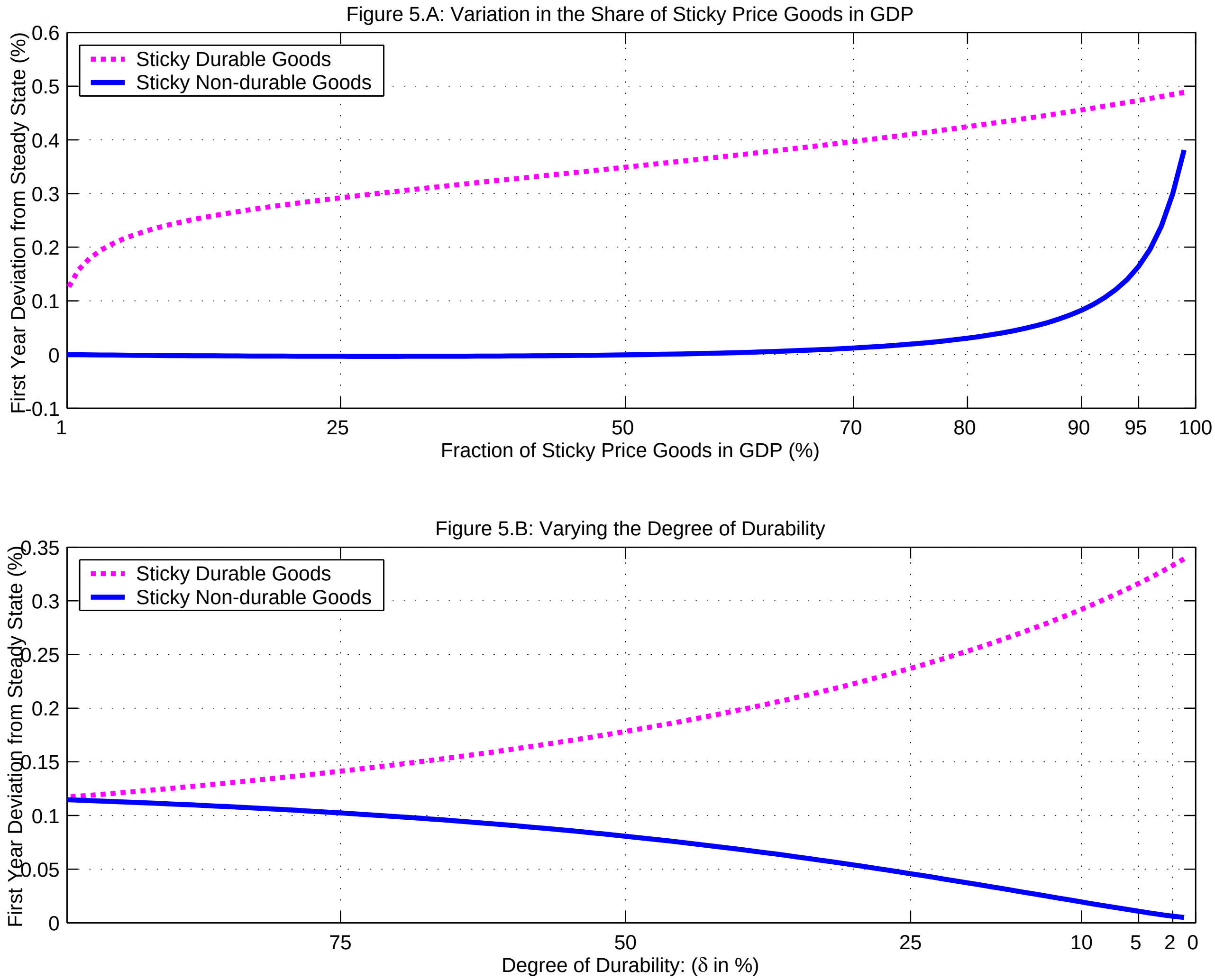

Figure 6: Complementarity between Durability and Non-durables

Figure 6.A: Flexible Non-durable Goods Prices

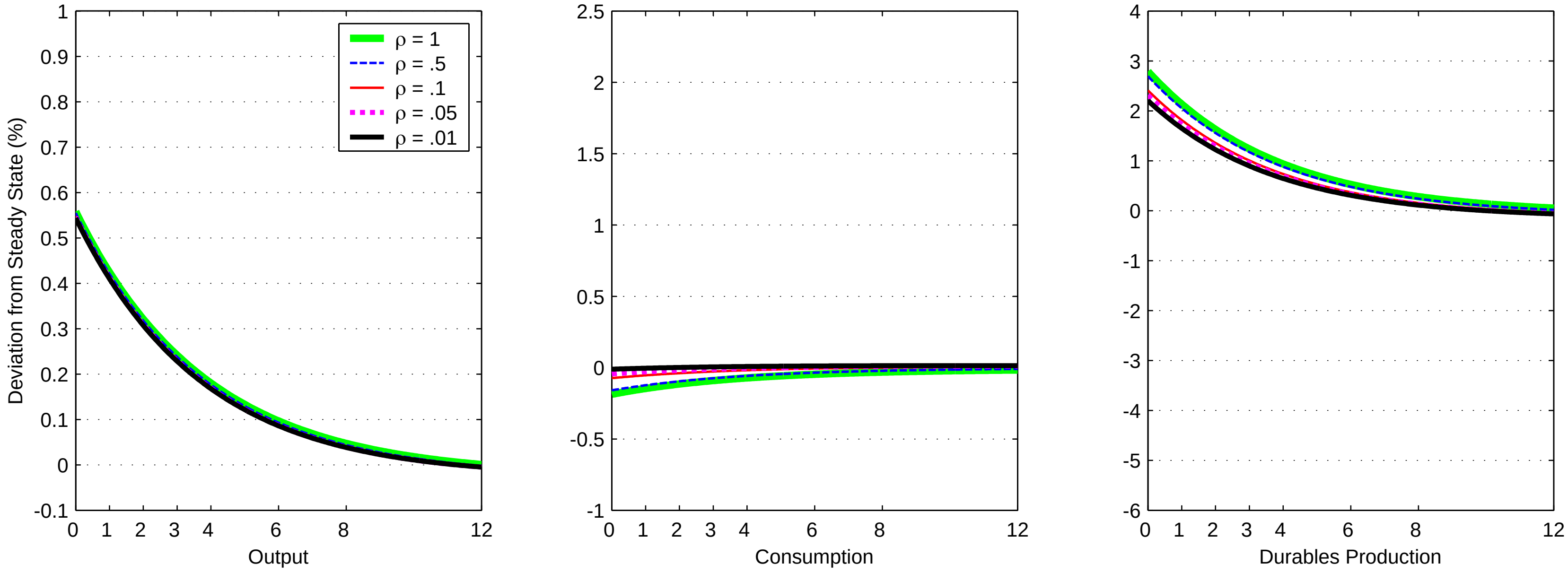

Figure 6.B: Flexible Durable Goods Prices

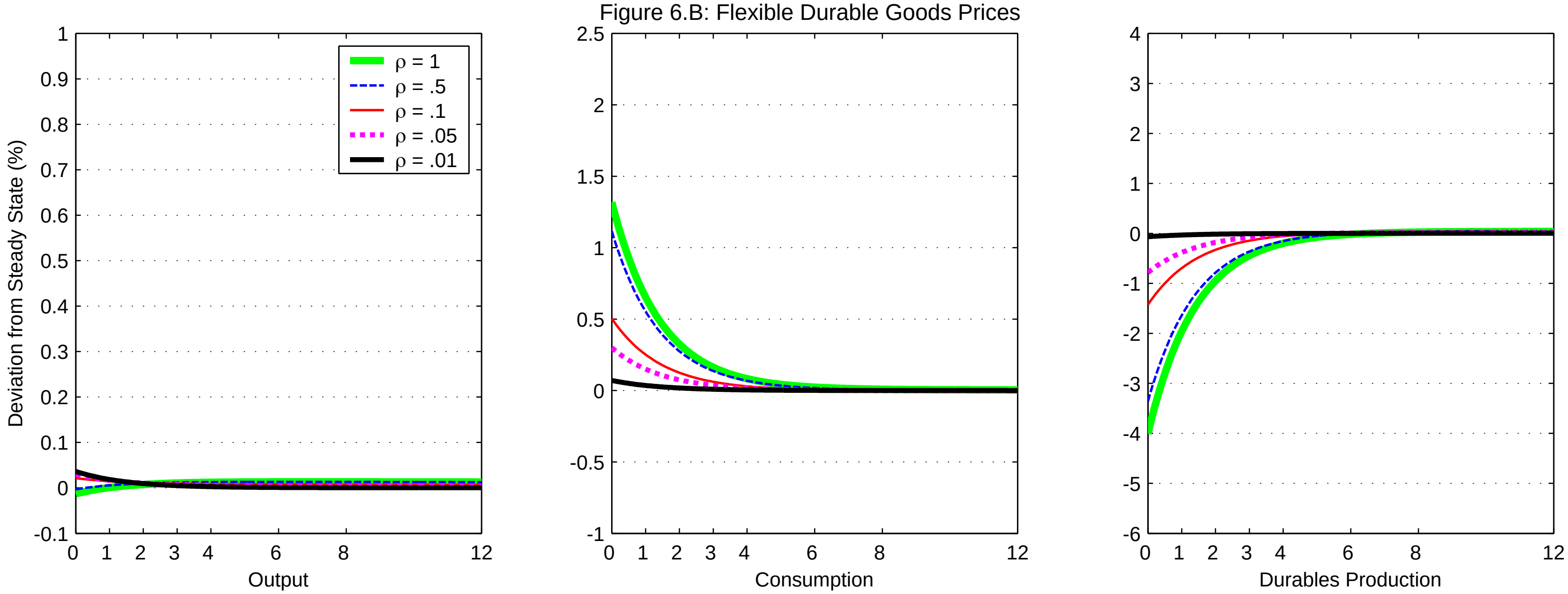

Figure 7: Sticky Wages and Durable Goods

Figure 7.A: Wage Rigidity when Durable Goods Prices are Sticky

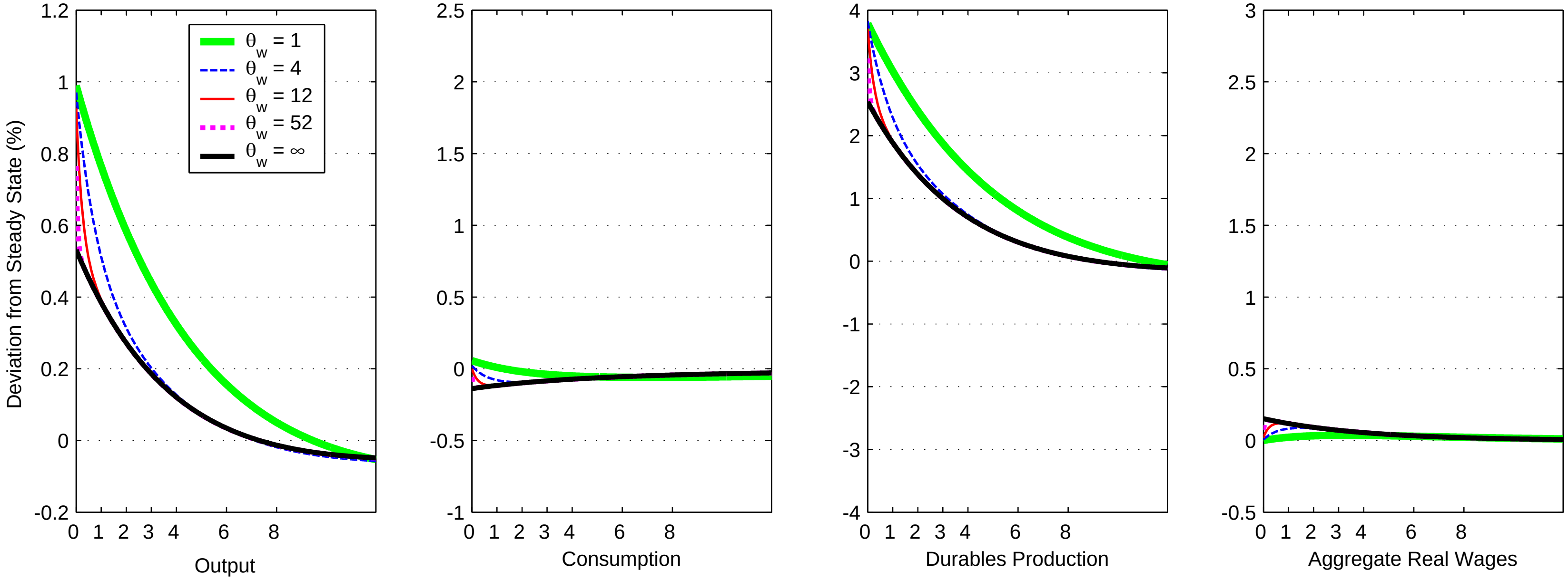

Figure 7.B: Wage Rigidity when Durable Goods Prices are Flexible