Do Flexible Durable Goods Prices Undermine Sticky Price Models?

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Abstract

The "neoclassical synthesis" sticky price model exhibits strange behavior when augmented with markets for durable goods with flexible prices. While in the data the output of durable goods responds strongly and positively to a loosening of monetary policy, in dynamic general equilibrium models a monetary expansion causes the output of flexibly priced durables to *contract.* In an instructive special case in which the only sticky prices are those of nondurables, the negative co-movement of durable and nondurable output exactly offsets and the behavior of aggregate output in the model is very similar to that of a model with fully flexible prices. This neutrality result is special, but the perverse response of durables to monetary policy is highly robust. The reason for the co-movement problem is the combination of a naturally high intertemporal elasticity of substitution for the purchases of durables and temporarily high factor prices associated with an economic expansion.

1. Introduction

Modern Keynesian theories of the monetary business cycle attribute central importance to nominal rigidities. In actual economies, many prices undoubtedly change very infrequently, but not all prices are equally sticky and some may be quite flexible. In business cycle modeling, however, surprisingly little attention has been paid to the fact that some goods prices adjust faster than others. Those multi-sector models that do consider differential price stickiness rarely highlight the potentially important differences between the nondurables sectors and sectors with consumer durables or durable productive capital.[1]

This paper investigates a model with both sticky price and flexible price sectors, and with both durable and nondurable goods. We find that it is not sufficient to specify how large the sticky price sector is relative to the flexible price sector; it matters crucially *which* sectors have sticky prices. The "neoclassical synthesis" sticky price model exhibits strange behavior when augmented with durables goods markets with flexible prices. In Keynesian macroeconometric models -- and in the data -- the output of durable goods is very procyclical, and in particular responds strongly and positively to a loosening of monetary policy. In the dynamic general equilibrium model, however, a monetary expansion causes the output of flexibly priced durables to *contract.* In an instructive special case in which the only sticky prices are those of nondurables, the negative co-movement of durable and nondurable output entails exactly offsetting effects, and the behavior of aggregate output in the model is very similar to that of a model with fully flexible prices. This neutrality result is special, but the perverse response of durables to monetary policy is highly robust.

Why durables? Spending in the nondurables consumption sector is subject to the logic of the permanent income hypothesis, and thus there is little room for consumers to intertemporally substitute in response to a rise in the relative price of nondurables. On the other hand, the stock of durables -- and hence its shadow rental rate -- is nearly constant over the modest horizon for which monetary disturbances might have real effects; the intertemporal elasticity of substitution for (purchases of) durables is nearly infinite. The result is that a small, temporary increase in the relative price of durables causes a large shift of expenditure away from that sector.[2] If the prices of durables are more flexible than those of nondurables, monetary expansion does indeed raise the relative price of durable goods – temporarily, since the effects of sticky prices are fairly

[1] Some notable exceptions that do consider differential price stickiness across sectors (and that we will refer to later in this paper) are Blinder and Mankiw [1984], Ohanian and Stockman [1994], and Ohanian, Stockman, and Kilian [1995]. Only the latter have capital as well as consumption goods in their model. These authors do not identify the location of the price flexibility in the capital sector as central to their results, though the comment on their paper by Leahy [1995] does.

[2] We have not formally studied the case of *storable*, though nondurable, consumption goods. It appears that at least some of the logic of this argument carries over to that case.

short-lived. Thus the model will predict that the durables sector contracts in response to monetary expansion and expands when monetary policy tightens.

More concretely, a monetary expansion raises spending at constant prices, resulting in increased output in the sticky price nondurables sector, increased factor demand, and higher marginal cost. While the markup on nondurables is squeezed below the desired level, the higher marginal cost associated with the increase in factor prices appears to the durables sector merely as an adverse cost shock; the period following a monetary expansion is an expensive time to produce. In the absence of a sufficiently large increase in the shadow value of durables, the sector contracts.

This scenario contrasts sharply with the conventional view of the role of durables embodied in informal Keynesian models. In those models, the desired stock of durables rises following a monetary expansion, more than offsetting the contractionary effects of the increase in factor prices.

The mechanism that leads to the contrarian behavior of the durables sector in our scenario is a manifestation of the general co-movement problem discussed by Murphy, Shleifer, and Vishny [1989]. In multi-sector general equilibrium models, shocks that cause an expansion in one sector often have a tendency to cause contractions in other sectors. For example, in a real business cycle model, temporarily favorable technology shocks in the consumption sector also cause a contraction in the durables sector and tend not to raise aggregate output – essentially for the same reasons. Temporary technology shocks are analogous to the temporary deviations in the markup (or "real marginal cost") in the sticky price model.

If there were no particular reason to believe that durables prices are, in fact, more flexible than prices of non-durable goods, our results would be of mostly academic interest. However, there are reasons to believe that durables prices are relatively flexible. One indication that durable goods prices have more flexibility is in the fact that the relative price of durables to nondurables falls in response to a monetary contraction. Following the Romer dates, the price of new houses falls by almost 10% relative to the CPI for nondurables. Automobile prices and the CPI for durable goods fall by roughly 5% relative to the CPI for nondurables.

There are also conceptual reasons to expect durables prices to be more flexible than prices of nondurables (except when the latter are purchased in large lots as producer goods). As a matter of *a priori* theory, durables are different because they are relatively expensive on a per-unit basis. If the explicit and implicit costs of negotiation have an important fixed component (i.e. one that is independent of the price of the good), there is more incentive to negotiate on the price of a durable good (see also Leahy [1995]). Furthermore, large durables often require considerable customization; this in itself necessitates negotiations, and the discussions about the exact nature of the good to be supplied are likely to be accompanied by negotiations about price. Zabracki, *et al*. [2002] present evidence obtained "in the field" on negotiations between customers and sales representatives of a large supplier of industrial durables to businesses, many of them with large accounts. They show that salesmen do in fact have (and exercise) considerable leeway to offer "deals" to major customers who express dissatisfaction with increases in list price. Finally, some durables are priced for the first time when they are sold. For instance, new houses do not have a price until they are sold.

Important previous papers that have studied modern business cycle models with flexible and sticky price sectors include Ohanian and Stockman [1994] and Ohanian, Stockman, and Kilian [1995]. The former does not include a durables sector, but it does feature a variable intertemporal elasticity of substitution in consumption in the two consumption sectors. As we emphasize later, the naturally high intertemporal elasticity of substitution in durable goods spending plays a central role in our paper. Ohanian, Stockman, and Kilian [1995] feature capital and present simulations displaying both perverse movements of the durables sector (although their exogenous one-period price stickiness cuts off the mechanism rather abruptly). Those authors do not analyze the underlying economics behind their simulation results; the present paper lays bare the conceptual underpinnings. The insightful comment on Ohanian *et al.* by Leahy [1995] did touch on many of the important economic effects but does not present our neutrality result, and thus leaves it something of a mystery as to why the overall output effect in Ohanian *et al.* is so close to zero.

In the next section we briefly document the pronounced behavior of durables sectors following monetary contractions. Not surprisingly, both the quantity and the relative price of durables fall sharply after such a contraction. These empirical facts set the stage for our analysis of the sticky price mechanism in environments with flexibly priced durables. Section 3 presents the basic framework used in the analysis. Sections 4 and 5 present the two main puzzles in our paper: the robust co-movement problems in the durable goods sectors and the potential for monetary neutrality in models with significant nominal rigidity. Section 6 presents simulations of the model and some extensions. Section 7 discusses possible resolutions to the co-movement problem. Section 8 concludes.

2. Response of Durable Goods Markets to Monetary Disturbances: Stylized Facts

The fundamental theme of this paper is the tension between theory and data with respect to the behavior of durable goods markets following a monetary policy disturbance. In the succeeding sections, we will demonstrate that dynamic general equilibrium sticky price models predict that an expansion in the production of flexibly priced durable goods accompanies the fall in their relative price in response to a monetary contraction. In this section, we establish that the durable goods puzzle is not merely an esoteric implication of theory, devoid of empirical relevance. We examine time series data on the prices and outputs of several categories of durables in the periods surrounding contractionary shifts in monetary policy. Durables prices are indeed more flexible than the prices of nondurables, in the sense that the relative prices of durables fall markedly following monetary contractions, and rise following monetary expansions. Production of durables, however, exhibits dramatic monetary policy "responses" of the conventionally presumed sign – in sharp contrast to the predictions of the model.

In recent literature, the most common approach to empirical study of monetary policy effects is to examine impulse responses to "identified" monetary policy shocks from a structural vector autoregression. Structural VARs have the advantage that, in the best case, they identify the truly exogenous component of monetary policy. However, in excluding from consideration the systematic component of monetary policy (e.g. the tendency of the central bank to contract in response to the worsening of inflation) structural VARs miss the lion's share of variation in the monetary policy instrument. In practice, the innovations in the federal funds rate may not be truly exogenous changes in monetary policy but rather the result of misspecification, omitted variables, or uninterruptible noise. Finally, we suspect nonlinearities that render the results of occasional large interventions particularly potent. Thus, our preference is to focus on the economy's behavior following a few clear-cut and dramatic changes in monetary policy.[3]

Specifically, we use the well-known *Romer dates* as indicators of pronounced monetary tightness.[4] 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 the important parts of monetary policy may be systematic. This approach has shortcomings. We would not even begin to claim that these monetary tightenings are exogenous. As Shapiro (1992) demonstrates, Romer dates tend to occur when inflation is high and rising and unemployment is low. The "shocks" we identify are few in number and are not ranked by magnitude. Finally, there is reason to believe that the Romer dates come too late to catch the inception of monetary tightenings (Bernanke and Mihov, [1998]) – a problem that is mitigated, however, by the flexible approach taken below.

We document the behavior of several economic variables before and after these events.[5] For any variable in levels we take the averages of x_{t+j}/x_t given that t is a romer date for j = -4, … 16. We compare this series with the averages of x_{t+j}/x_t for all dates (again for j = -4, … 16). 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 see the events "leading up" to a Romer date. In addition, we suspect that Romer dates may lag the actual changes in policy. Bernanke and Mihov [1998] argue that Romer dates occur when their index describing the stance of monetary policy (the Bernanke-Mihov index) is

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[3]Because there is not universal agreement on the relative merits of the two approaches, in an appendix we present a VAR for several of the variables that we are interested in. Qualitatively, the two procedures give strikingly similar results. Specifically, durables respond more than nondurables to monetary policy "shocks" and the relative price of durables to nondurables is positively related to monetary expansions. The effects are statistically significant and quantitatively nontrivial. However, not surprisingly, the magnitudes of the VAR impulse responses are more modest.

[4] The six Romer dates all correspond to monetary contractions. Barsky and House (in preparation) combine the information in the Romer series and the Bernanke-Mihov series to construct an analogue of the Romer dates for monetary expansions. We find that the effects of these monetary expansions on the durables markets are similar (with opposite sign) to the effects of the Romer dates, and if anything are even larger in magnitude.

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

at a trough. This suggests that the actual change in monetary policy was made prior to the date.

Before proceeding to the results we should make a remark concerning the interpretation of the "trend" by which we mean the path of the ratios x_{t+j}/x_t over the horizon j = -4, … 16, averaged over all dates. Statistically, this average path is the best predictor of the relative size of the variable x, j periods after (or before) an arbitrary date t. Economically, this corresponds to the trend growth rate. For some variables following a Romer date, there is a tendency to fall below "trend" and not recover. This is due to the fact that the timing of the Romer dates is endogenous. Typically Romer dates occur when the economy is "above trend". So, when a variable falls relative to its trend growth path, some of the response should be interpreted as simple mean reversion. Again, we are not claiming that these effects are due to exogenous changes in Federal Reserve policy.

Figures 1.a, 1.b, and 1.c show the average behavior of several economic variables in the quarters following a Romer date. One thing to notice is that the response of these variables is much more dramatic than responses following "shocks" in a VAR. The main reason for this difference is that the "events" we are considering (i.e. Romer dates) do not correspond to small "shocks" to a stable monetary policy rule but rather represent a fundamental change in monetary 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 (see Figure 1.c).

There are several regularities to point out. First, from Figure 1.a, we see that following a Romer date, durable goods sectors contract very sharply while nondurable goods (and overall GDP) do not. Relative to levels in the reference period (the Romer date), housing starts fall by approximately 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% after eight quarters. They remain more than 10% below the level in the base date for eight quarters (from *t*+4 until *t*+11).[6] Finally, real durables purchases fall by 12.5% relative to the reference date. The trough occurs eight quarters after the event. In contrast, nondurables and GDP as a whole react much less dramatically. Real purchases of nondurables rise *above* "trend" immediately following the event (although insignificantly) 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%.[7]

In addition to the large effects on durables spending there are significant changes in the relative prices of durables and nondurables following a Romer date. The price of new houses relative to the CPI for nondurables falls by 12% in comparison to the reference date.[8] The trough occurs nine quarters after the Romer date. The relative price of cars (measured by the CPI for new autos relative to the CPI for nondurables) falls by more than 6% relative to the base date after five to seven quarters. Note that the relative price of cars has been falling over time (as shown by the dashed line) so this drop is not as significant. Relative to "trend" the maximum drop is only 5%. The price of durables relative to non-durables (both measured by their respective CPIs) falls by 4.8% relative to the reference date (again the trend for the relative price of durables is negative; relative to the trend growth rate, the drop is only 3.7%).

Figure 1.c shows the unemployment rate, the federal funds rate, the rate of inflation and the total level of employment. All of these variables respond according to conventional wisdom. The unemployment rate rises by almost 3% following a Romer date. Total employment falls only slightly though it has a much slower rate of growth than average. According to our data, the average increase in the federal funds rate is almost seven percentage points from four periods before the Romer date to seven quarters afterwards. Most of this increase is due to the very sharp increases in interest rates in the early 1980s. Interestingly, following Romer dates, inflation continues to rise. It does not begin to drop until three years after the base date.

To summarize, durables respond very significantly to changes in monetary policy while nondurables are not strongly affected. Following a monetary contraction, durable goods (houses, cars and aggregate real durables) all contract sharply. In particular,

[6] The point estimate is below 10% again 13 quarters following the shock (but not in quarter 12).
[7] Aggregate employment follows a similar pattern (Figure 1.c).
[8] This number is for the *median* house price. The number for the average house price is similar.

housing starts fall by more than 30%. In addition, the relative price of durable goods to nondurable goods appears to fall significantly after a monetary contraction. Among the more significant sectors in this regard is the housing sector. The relative price of houses to nondurables falls by roughly 10% relative to its level on the date of the policy shift.

3. Framework

In this section, we consider a dynamic economy with many industries or sectors. Some industries produce durable goods while the others produce non-durables. In addition, some of the goods have sticky prices while others have flexible prices. We assume that there is at least one industry that produces durables and has flexible prices.

For this simple model we will assume that capital is fixed in each industry and that labor can flow freely across industries. Later we will relax both of these assumptions. One consequence of labor mobility is that the nominal wage rate W_t will be the same across industries.

Because our focus is on the role of sticky prices in the business cycle, we assume that firms have constant desired markups over their marginal costs of production. Any deviations from these desired markups must come from nominal rigidities. Said differently, the sticky prices in the final goods markets do all of the work in our model.

3.1 Household behavior

Consumers get utility from both nondurable consumption goods and durable consumption goods. We denote a typical durable good as d_{jt} and a typical nondurable good as c_{jt}. Total utility is time separable and additively separable in labor.

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

N_t is labor supplied at date t. The additive separability of labor is important for our results. We will return to this point later.

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

$$\sum_j P_{jt} x_{jt} \leq W_t N_t + \Pi_t + T_t + \left(1 + i_{t-1}\right) S_{t-1} - S_t ,$$

where Π_t are profits returned to the consumer through dividends, T_t are nominal transfers (or taxes), S_t is nominal savings and i_t is the nominal interest rate. Notice that for nondurable goods $c_{jt} = x_{jt}$ while for durable goods we have:

$$d_{jt} = x_{jt} + d_{jt-1}\left(1 - \delta_j\right).$$

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

<u>Labor Supply and the Demand for Goods and Services</u>

Taking prices as given, the consumer chooses x_{jt} and N_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 marginal utility of acquiring an additional unit of good j (good j can be either a durable good or a nondurable good).

Purchasing an additional amount of any good results in the following change in utility:

$$\gamma_{jt} - \lambda_t P_{jt} . \tag{1.1}$$

If the consumer is maximizing utility, this must be zero. These conditions (one for each good j) imply that the marginal utility per dollar must be equal across goods and jointly represent the consumer's demand functions given the amount of money he wishes to spend.

The first order condition for the supply of labor (N_t) satisfies $v'(N_t) = \lambda_t W_t$. Combining this with (1.1) gives a set of conditions that relate labor supply to the demand for goods and services:

$$v'\left(N_t\right) = \left(W_t / P_{jt} \right) \gamma_{jt} . \tag{1.2}$$

This says that the utility cost of an additional unit of labor must be exactly balanced by the benefit of having W_t extra dollars to spend on any of the goods in the economy. This condition must hold for every good j.

Money Demand

For simplicity we assume that money demand is proportional to nominal purchases:

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

Here, M is the nominal money supply (the "velocity" of money is 1). Money is injected into the economy through lump sum transfers T_t to the agents (T_t can be negative). Of course, money demand might also be related to the nominal interest rate (an "LM curve") or other macroeconomic variables. Modifying the model to allow for such interactions is easy and does not alter our basic findings. The important feature of money demand is that when the money supply increases, firms have incentives to raise their prices.

3.2 Firm Behavior

Firms convert labor input into outputs according to their production functions.

$$x_{jt} = F_j(n_{jt})$$

We allow for 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.

The firms set nominal prices at or above nominal marginal costs. If the firms are competitive then $P_{jt} = MC_{jt}$ while if they are monopolistically competitive $P_{jt} = \mu_{jt} MC_{jt}$ where $\mu_{jt} > 1$ is a markup. The nominal marginal cost of producing an extra unit of output is the cost of hiring an additional unit of a production input times the number of inputs required to produce an additional unit. In this simple case, labor is the input to production so $MC_{jt} = W_t\,((\partial n)/(\partial q))=W_t\,[MP_{jt}^N]^{-1}$ where MP_{jt}^N is the marginal product of labor.

Sticky Prices

The precise form of sticky prices is not important for our basic results. In the simulations presented in the paper we adopt a Calvo price setting structure. For now all that we require is that nominal rigidity prevents some firms from maintaining their desired markups. Firms with sticky prices will have *effective* markups that change following a monetary shock. Some firms that had "correct" markups will not be able to readjust their prices in the face of a shock. Furthermore, firms that can reset their price now (or that endogenously choose to incur a “menu cost” to adjust their price) may decide to set a price that makes their *actual* markup different from their long-run desired markup. Setting the price to generate the current desired markup may cause the firm to be stuck with a price that is incorrect for future periods. Thus for firms with sticky prices, μ_{jt} will fluctuate with changes in the money supply. This is the driving force behind modern sticky price models.

Firms with perfectly flexible prices simply maintain their desired markups – so for these firms $\mu_{jt} = \mu_j$. This last feature stems directly from the assumption that firms desire constant markups over their marginal costs of production. In a model in which desired markups vary endogenously with the business cycle, even the flexible price firms could behave as though they had sticky prices.

4. The Co-movement Problem

Consider an expansion in the money supply. Firms with sticky prices cannot change their prices and, because $P > MC$, produce to meet demand. This requires increasing employment, which bids up the nominal wage. Flexible price firms raise prices to cover the increase in nominal marginal costs which come from rising nominal wages. Industries with sticky prices experience expansions in production and employment. But what happens in industries with flexible prices?

There are good reasons to expect flexible price firms to curtail production following a monetary expansion. First, because the flexible price goods maintain their markups while the sticky price goods see their effective markups fall, flexible price goods become relatively more expensive than sticky price goods. The rise in the relative price of goods with flexible prices means that consumers should substitute away from these products.

Second, to the extent that employment rises following a monetary expansion, real wages will rise. In our model this comes from the increasing marginal disutility of labor ($v'(N_t)$) (i.e. the labor supply curve slopes up). More generally, as the economy expands, pressure on input markets (labor markets, markets for fuel and raw materials, etc.) will rise. Firms with sticky prices simply "suffer through" these periods of high production costs. Their markups are below their desired level but, provided that their price is still above marginal cost, they will allow production to expand. Firms with flexible prices see things very differently. To these firms, all that has happened is that their real costs of production have gone up. Workers who were recently willing to work for a lower real wage now require more real compensation from their employers. In the face of rising costs, firms with flexible prices should again be tempted to contract.

While these observations would be sufficient in a partial equilibrium model, in general equilibrium models it is not enough to say that, *ceteris paribus*, a rise in relative prices will depress demand, or that, *ceteris paribus*, a rise in real marginal costs will reduce production. In general equilibrium, other features of the economy may change in addition to costs and relative prices. In particular, the *demand* for flexible price goods and services may be expected to increase. This is especially true if we are imagining that the economy expands after an increase in the money supply. A simple example of such an effect would be a complementarity between consumption of a sticky price good and a flexible price good. In this case, even though it has become more costly to produce, demand may increase enough to warrant an increase in production. If there is enough complementarity between goods, then sticky prices in one sector can cause an expansion in other sectors even if the other industries have flexible prices.[9]

For flexible price industries that produce durable goods though, these demand spillovers will not occur. Under standard assumptions, the demand for durable goods will not change much over a business cycle. As a result, for these goods, costs rise but demand does not. The only equilibrium outcome left is a contraction for such sectors.

[9] See for example Stockman, Ohanian and Killian [1995].

There are two reasons why this happens. First, the marginal utility of an additional durable depends on the total stock of the durable rather than the flow of new production. For durable goods like housing, this stock will not change much over the course of a typical business cycle. Second, the marginal utility of acquiring a unit of a durable is the sum of flow utilities extending into the distant future and as a result does not depend heavily on short run business cycle conditions.

More formally, let j be an arbitrary durable good. The marginal utility of acquiring an additional unit of this good at date t is γ_{jt} which is:

$$\begin{aligned}\gamma_{jt} &= MU\left(d_{jt}\right)+\beta\left(1-\delta\right)MU\left(d_{jt+1}\right)+\beta^2\left(1-\delta\right)^2 MU\left(d_{jt+2}\right)+\ldots \\ &=\sum_{k=0}^{\infty}\left\{\beta\left(1-\delta\right)\right\}^k MU\left(d_{jt+k}\right).\end{aligned} \tag{1.3}$$

If the marginal utility of durables depends only on the stock of durables then γ_{jt} will not change much since d_{jt} does not move much over the cycle. On the other hand, the marginal utility of durables could depend (positively or negatively) on the consumption of other goods. If d_{jt} is highly complementary with another good (say a good that expands during the business cycle) then $MU(d_{jt})$ might change even if d_{jt} did not. However, for long-lived durables, this will still not cause γ_{jt} to change significantly. If the expression (1.3) places a lot of weight on future terms (due, for instance, to low depreciation rates or low discount rates), then for complementarities with other goods to matter we will require very high degrees of curvature in the utility function (i.e. $((\partial(\partial u/\partial d_{t+j}))/(\partial c_k))$ will have to be *very* large) to cause a substantial change in γ_{jt}.

The conclusion we draw from this discussion is that to a first approximation $\gamma_{jt} = \gamma_j$ (the steady state shadow value of an additional durable) over a business cycle. This approximation will be very good for durables with strong stock-flow distinctions (i.e. low depreciation rates).

Consider a durable goods industry with a flexible price. Because the good is a durable γ_{jt} is going to be roughly constant. For this industry, the labor supply condition is $v'(N_t) = (W_t/P_{jt})\,\gamma_{jt} \approx (W_t/P_{jt})\,\gamma_j$. Because the sector has flexible prices (by assumption) the price of this good is a constant markup over its marginal cost $P_{jt} = \mu_j (W_t / MP_{jt}^N)$. Combining these expressions (equating labor supply and labor demand) implies that:

$$v'(N_t) = \frac{\gamma_j}{\mu_j} MP_{jt}^N \tag{1.4}$$

If aggregate employment rises in response to an increase in the money supply then $v'(N_t)$ rises, reflecting the fact that workers are being drawn up their labor supply curves. To maintain the equality, the right hand side of equation (1.4) must also rise. Since the shadow value of the good (γ_j) and the firm's desired markup (μ_j) stay the same, the marginal product of labor must rise. As a consequence, employment in this durables sector falls.

Both durability and price flexibility are important for the strong co-movement problem we present. If the good were a nondurable then marginal utility would rise quickly with reduced consumption. For a durable however, marginal utility depends on the stock of the good rather than the flow of production. As a consequence, production can fluctuate wildly without much impact on the flow of utility to the consumers.

One feature of the model above is that labor is homogeneous and can move freely across sectors. Another way of saying this is that there is simply one aggregate labor supply curve governed by $v'(N_t)$. The argument we gave above does not work when there are separate labor supply curves for each industry. Industry-specific labor supply curves insulate sectors from rising costs in other areas of the economy and as a result might be important in mitigating the co-movement problem. Unfortunately, the best this modification can do is to render the durables sector acyclical. Because we have already seen that durables are the sectors that appear to respond most to monetary policy, we regard such acyclicality as a particular case of the co-movement problem.

Consider a modification of the model to allow for separate labor supply relationships. Utility is given by:

$$U = E\left(\sum_{t=0}^{\infty} \beta^t \left[u\left(c_{1t}, c_{2t}, \ldots, c_{jt}, \ldots d_{1t}, d_{2t}, \ldots d_{jt} \ldots\right) - \Phi\left(\left\{N_{jt}\right\}_j\right)\right]\right)$$

where N_{jt} is labor supplied to sector j at time t and Φ is an aggregator. Previously we assumed that Φ was simply a convex function $v(.)$ of the sum of the N_{jt}. To keep things simple take Φ to be a sum of convex functions $\Phi = \sum_j v_j\left(N_{jt}\right)$. This effectively isolates each sector's labor supply pool (there is no substitution of labor at all across the industries).

Now, increased employment in other sectors during a monetary expansion will drive up the cost of producing only those goods. The pressure on labor markets in other sectors will have no affect on the supply of labor in flexible price sectors. The labor market clearing condition in a durable sector with flexible prices is now:

$$v_j'\left(N_{jt}\right) = w_{jt}\frac{\gamma_{jt}}{P_{jt}} = \frac{MP_j^N}{\mu_j}\left(N_{jt}\right)\gamma_j \qquad (1.5)$$

where the second equality again follows from durability (resulting in a constant marginal utility γ_j) and price flexibility (giving the constant markup μ_j). This is one equation in the one unknown N_{jt}. Thus, in the extreme case of no labor mobility at all across sectors, durable goods with flexible prices will not respond at all to monetary shocks. To the extent that there is any labor mobility across sectors, durable goods with flexible prices will contract after a monetary expansion.

This special case of the co-movement problem highlights the difficulty that factor mobility poses for the model. When factors are totally bound to one sector or another, durable goods sectors will not vary with the business cycle. Allowing for factor mobility makes the co-movement problem *worse*. Inputs leave the durable sectors and flow to the nondurable sectors causing durable goods production to fall. Thus, although frictions in labor reallocation help to alleviate the co-movement problem, they cannot solve it. The best they can do is to make the sector acyclical.

The reason that the co-movement problem is so tough for durables sectors is a combination of two effects. First, the demand for these products does not rise much because the shadow value of additional durables is inherently stable. Second, the real prices of inputs (in our model, labor) naturally rise when the economy expands.

Ironically, one of the reasons for the popularity of sticky price models is that they generate procyclical real wages together with monetary non-neutralities. The problem is that for sectors with flexible prices, high real wages are simply high costs of production. If demand does not rise but costs do, firms reduce production.

5. Sticky Prices and the Neutrality of Money

So far we have focused on the co-movement problem in isolation. Now we briefly turn our attention to the behavior of aggregate employment, output and prices. In this section we show that if *all* durables have flexible prices, production has constant returns to scale, and factors can move freely across sectors, then money is neutral with respect to aggregate output and employment regardless of the degree of nominal rigidity in the nondurables sectors.[10] The percentage change in the aggregate price index (the model's version of the GDP deflator) will be equal to the percentage change in the money supply. This will be (approximately) true regardless of how much price rigidity there is in the nondurable sectors and regardless of the ratio of nondurables to durables. Even if the nondurables sectors have very sticky prices and even if there are many more nondurables than durables in GDP, money will be approximately neutral.

<u>Labor Inputs Only</u>

The simplest way to see the neutrality result is to consider a case in which production requires only labor and that $x_{jt} = A_j N_{jt}$ in every sector (so that production has constant returns to scale). This implies that the marginal product of labor is constant at A_j. The labor market clearing condition for a durable goods sector (d) implies that

$$v'\left(N_t\right) = \frac{\gamma}{\mu} MP_{dt}^{N}$$

but because $MP_{dt}^{N} = A_d$ we have one equation in the one *aggregate* variable N_t. The other terms are constants because of flexible prices (constant μ) and durability (constant

[10] To avoid having a composition of output effect, we also require that all the sectors have the same steady state markups. See Basu and Fernald [1995]

γ) in this sector. The level of employment that solves this equation following a monetary shock is the same as the employment in the steady state. As a result, aggregate labor will not vary over the cycle and money will be neutral.

Multiple Factors of Production

The neutrality result continues to hold in environments with capital inputs. Specifically, assume that production in each sector has the constant returns to scale production function:

$$x_{jt} = F(k_{jt}, n_{jt})$$

(we assume that F is symmetric across sectors). Because factors can flow freely across industries, nominal wages and rental prices will be equal in each sector. In addition, the firms will always choose a combination of inputs to minimize their costs (given their output decision). Since the production function is homogeneous of degree one, cost minimization implies that the capital-to-labor ratios will equalize across sectors regardless of whether it has sticky prices or flexible prices. Industries that increase production do so by hiring capital and labor in the same proportions as other industries. Summing over all sectors gives us:

$$\frac{k_{it}}{n_{it}} = \frac{k_{jt}}{n_{jt}} = \frac{K_t}{N_t}$$

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

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

Finally, returning to the labor market clearing condition in the durable goods sector, we have:

$$v'(N_t) = \frac{\gamma}{\mu} MP_{jt}^{N} = \frac{\gamma}{\mu} \varphi\left(\frac{K_t}{N_t}\right) \tag{1.6}$$

Like all of the other durable goods, the aggregate capital *stock* does not move much over the cycle. Because K_t is a "slow moving" component of the model we can safely treat the aggregate capital stock as approximately fixed over business cycle horizons. This gives us, again, one equation in aggregate employment (N_t) and, as a result, employment is (approximately) constant over the cycle and money will be approximately neutral.

<u>Discussion</u>

The neutrality result is an extreme case of the co-movement problem. It leans heavily on flexible inputs, and constant returns to scale in production. Inputs must be fully mobile. If there were frictions to factor mobility then when the durable goods sector expands or contracts, the effective marginal product of labor will fall or rise in that sector. Note that investment adjustment costs are a simple form of a diminishing effective marginal product of labor and thus would break the neutrality result easily.

The constant returns to scale assumption is necessary to ensure that the marginal product of labor in equation (1.6) does not move with large variations in employment and production in any one sector. As a result, the durable goods sector can expand or contract sharply to "free up" or "soak up" resources to or from other industries.

It is also important to point out that *all* durable goods must have flexible prices for the neutrality result to work. If just one durable good has sticky prices, then following a monetary expansion there will be a dramatic expansion in the production of that good. Constant returns to scale and fully mobile factors of production will imply an almost infinite substitution from flexibly priced durables sectors to sticky price durables sectors.

6. Simulations

In this section we use a computable general equilibrium model to demonstrate our results. To give the reader a sense of how a "normal" sticky price model responds to a monetary shock, we begin with a standard New Keynesian model in which both the durable sector and the nondurable sector have equally sticky prices. In all of our simulations, we model sticky prices with a Calvo price setting mechanism.

Symmetric Price Rigidity

In the benchmark model, prices are equally sticky throughout the economy. We assume that the half-life of exogenous price rigidity is six months (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 half-life of six months requires an annual Calvo parameter of $2ln(2) = 1.3863$, meaning that on average firms get to reset prices 1.4 times per year.[11] This is a considerable amount of exogenous price rigidity. Bils and Klenow [2002] find that prices of most consumer goods are reset, on average, once every four months which suggests a Calvo parameter closer to 3.

The durable in this model functions only as a final good, not as capital (the results are qualitatively the same when the durable functions as productive capital). Production is linear in labor in each sector. We assume that 75% of total GDP consists of nondurable production. The aggregate labor supply elasticity and the intertemporal elasticity of substitution are both set to 1. The depreciation rate for the durable good is 10% annually. The remaining details of the model are left to the appendix.

Figure 2 shows the impulse response of our benchmark model to a permanent, unanticipated 1% increase in the money supply. In the figure, C is aggregate production (and consumption) of the nondurable good and X is the production of the durable; in addition, 100 periods corresponds to one year. While prices adjust, employment and output rise. In the first quarter following the shock (the first 25 periods in the figure), total output rises by 0.83%.[12] Of course if prices were more rigid the model would generate greater responses. For instance, if firms could change prices only once every two years (on average) then output would rise by 0.93% in the first quarter.

Production of the durable good rises sharply following the shock (3.8% in the first quarter) while production of nondurable consumption good rises by much less. Because the stock of durables does not change much over the cycle, production of the durable good can be varied considerably without changing the shadow value of the durable significantly. On the other hand, nondurable consumption cannot change without

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[11] More precisely, the probability of a price being stuck for a whole year is $\theta = \exp\{-1.3863\}$.

[12] The plot makes it look like output rises by 1% because it is plotting the first 100^{th} of a year rather than the first quarter. Note that because output is linear in employment, the employment response is also 0.83%. Finally, for the standard New Keynesian model with productive capital, the same experiment implies that employment and output increase by roughly 0.79% and 0.52%, respectively.

significant changes in its marginal utility. Said another way, purchases of the nondurable good obey the permanent income hypothesis (PIH) while purchases of the durable do not.[13] [14]

Flexible Durables Prices and Sticky Nondurables Prices

Figure 3 shows the response of the model when only the nondurable good has sticky prices. Again, we consider a permanent increase in the money supply of 1%. This figure illustrates two of the central results of our paper. First, surprisingly, even though the production of the nondurable good accounts for 75% of total GDP, output barely changes after the shock. GDP – and consequently aggregate employment – rises by only 0.1% in the quarter following the shock. Even though most prices in this economy are sticky, money is approximately neutral with respect to aggregate employment and aggregate output. The source of this neutrality is, of course, the co-movement problem. Consumption rises by 2.45% and investment falls by roughly 7% in the first quarter.

Notice that both the nominal interest rate and the real interest rate fall after the monetary expansion. Thus, even though durables are perceived as "interest sensitive" components of aggregate expenditure, the interest rate effect does not manage to raise demand for these sectors.

Sticky Durables Prices and Flexible Nondurables Prices

To show that this result is not simply a consequence of having one sector with sticky prices and another sector with flexible prices we now consider the opposite case -- sticky durables prices and flexible nondurables prices. Recall that the durables industry is the smaller industry so only 25% of GDP has sticky prices in this case. Figure 4 shows impulse responses for the same 1% increase in the money supply.

Even though durables (the sticky price goods) only make up 25% of GDP, output rises by 0.45%. The output response is almost five times greater than in the case with

[13] See Mankiw [1982].

[14] Note that nominal interest rates rise after the monetary expansion. Most of this is due to anticipated inflation rather than changes in the real rate of return. In models with capital, increases in employment cause the marginal product of capital to rise. The link between the marginal product of capital and the real interest rate implies that in sticky price models with capital, real interest rates also have a strong tendency to rise (see Tobin [1955] and also Sargent [1987] chapter 3).

sticky nondurables prices. In fact, the increase in output is more than half of the increase when all prices were sticky. Notice that the co-movement problem that was so pronounced in the first case is greatly alleviated. Although consumption falls by 0.45% in the first quarter, durable goods production rises by 3.18 percent. This is much closer to the behavior we see in the data.

This “reverse” experiment shows that it is not simply the fact that one sector is expanding while the other is contracting due to relative price changes. Instead, whether output and employment respond to money shocks depends on whether the durable goods sector has sticky prices. Very flexible durable goods prices result in monetary neutrality even if the nondurables prices are very sluggish. However, the opposite is not true. Money is not neutral if nondurables prices are flexible but durables prices are sticky.

Figure 5 plots the response of output in the first quarter following the shock for our model as we vary the share of the sticky price sector. In the figure, the solid line represents the model when durables prices are sticky. The dashed line is for the model with sticky prices for the nondurables sector.[15] As the figure shows, the responses of the economy depend importantly on which sector has sticky prices. Not surprisingly, as the share of sticky price sectors falls, the output response gets smaller. When the sticky price goods are nondurables, however, the output response falls drastically as we reduce the fraction of sticky price sectors in GDP. Even when 80% of GDP has sticky prices, the output response is less that 20% of the response when all prices are sticky. In contrast, when the durables have sticky prices the fall in the output response is much less severe. Even when only 20% of GDP has sticky prices, the response of output is still half of what it is when all prices are sticky. To the extent that macroeconomists are concerned with the real effects of money, we get greater increases in output and employment when 10% of GDP are durables sectors with sticky prices than when 90% of GDP are nondurables sectors with sticky prices. The message of this experiment is clear: in an economy with durable goods, sticky prices are important *only* if some durable goods have sticky prices.

7. “Resolving” the Co-movement Problem:

[15] Because we are changing the share of durables in GDP and because the production of durables is inherently more volatile than for nondurables, we normalized the lines by the response when all of GDP consists of either the durable or the nondurable good. The non-normalized graph looks similar.

It is difficult to resolve the co-movement problem in the sticky price modes that we have considered. In this section, we consider some modifications to our model and ask whether they might be part of a solution to eliminate negative co-movement.

7.1 Output Effects

One way to cause investment in durable goods to rise when the economy expands is to explicitly tie such investment to output. Then, even though the costs of production are rising, investment might increase due to the expansion in GDP. Here we discuss three ways of achieving this: (1) the investment accelerator, (2) the financial accelerator, and (3) endogenous countercyclical markups.

The Investment Accelerator

There are other reasons, beyond consumption smoothing motives, why investment (in durables or capital) might increase when output rises. We discuss two of them under the general heading of investment accelerators.

First, the return to capital goods rises when employment is high. Having more workers means that the marginal product of capital is high. This could serve to stimulate investment. Clearly, the more aggregate employment responds the more this accelerator channel will work. If labor supply elasticities are large, employment will rise more in an expansion which will increase the demand for capital.

There are two problems with this story. First, it requires a significant and prolonged increase in employment. If monetary business cycles are short-lived, the increase in the payoff to new capital will be relatively small and consequently will bring forth only a small increase in investment. Second, this interpretation of the investment accelerator only applies to durables that function as *productive capital*. The demand for durables that are not used in the production process (residential housing for instance) will not respond to changes in employment.

A second reason that investment might respond to output is complementarity between the consumption of durable and nondurable goods. Then, if production of the nondurable good expands, the desired stock of durables will rise.

While a high degree of complementarity sounds promising on its face, there are additional consequences to this type of demand spillover. Large complementarities tie production of nondurable goods to the *stock* of durable goods. If the stock of durables cannot rise quickly, the production of nondurable goods will not rise either. If the stock-flow distinction is strong enough, then high complementarity will create an *additional* co-movement problem in the associated non-durable good.

In our quantitative model, because the durable has a low depreciation rate, a high degree of complementarity *strengthens* the neutrality result. Figure 6 shows three simulations of the benchmark model with flexible durables prices. The top panel is the benchmark model we began with. Output does not change in response to monetary stimulus, durable goods production falls and nondurable production rises. The middle panel shows the same model with a modest amount of complementarity between durable consumption and nondurable consumption. Now, in addition to output being approximately neutral, industry specific output responds less to the money shock. The bottom panel shows an extreme case of complementarity. The neutrality that was present only in aggregate employment and GDP has now spread to a neutrality condition that holds sector by sector.

Liquidity Constraints and the Financial Accelerator

Another way to relate investment demand (and production) to aggregate output is with liquidity constraints or countercyclical external finance premiums (the *financial accelerator*).

Suppose that the demand for durables is primarily composed of people who need to borrow to acquire the durable. Furthermore, assume that many of these people face binding liquidity constraints on their borrowing. These customers would like to borrow against their future income to buy more durable goods but they are up against their borrowing constraint. As a result, these consumers will spend any additional income on durable goods even if nondurable goods become relatively cheaper for them. For these customers $\gamma_{dt} > \lambda_t P_{dt}$; this breaks the link in the benchmark model between the marginal utility of an extra durable and its price.

In addition to a pure borrowing constraint story like the one above, many models imply that the severity of liquidity constraints is inversely related to cash flow or collateral (this is the main idea behind the *financial accelerator* hypothesis). These models imply that in addition to spending additional income on durables, extra income will also relax the borrowing constraints themselves.

Endogenous Countercyclical Markups

Finally, the optimal markup μ_t for the durable goods producers might vary systematically with output. In this case, the sector may behave like a sticky price sector even if its prices are flexible. One rationale for this type of behavior is a procyclical elasticity of demand. If the marginal customers are the most price sensitive ones, then an expansion causes the demand side of the market to become more price elastic. As a result, the optimal markup falls endogenously. This will increase sales and production.

7. 2 Production Complementarities

An important feature of our framework is the assumption that labor is additively separable in the utility function. Complementarity between labor supply and nondurables can go a long way towards resolving the co-movement problem. As production of nondurables expands, labor supply will increase. Increased labor supply will lower costs of production throughout the economy and could encourage production in the durables sectors if the effect is strong enough. Of course, if labor supply is complementary with the durable good then this will reinforce the co-movement problem (and the neutrality result).

Labor supply complementarity is a special case of production complementarities in general. Positive externalities in the production of nondurables will reduce the marginal costs of production in the durable goods sector and may cause production to increase.

7.3 Sticky Wages

Although we assumed that the price of the durable good was flexible, if wages (or any input price) are sticky then production will have reason to rise following an increase in the money supply.[16]

Figure 7.a shows the impulse response function for the two sector model to a permanent 1% increase in the money supply under the assumption that wages are reset on average once per quarter. Wage setting is also modeled with a Calvo mechanism. We maintain the assumption of sticky nondurables prices, and flexible durables prices.

The sticky wages can easily break our neutrality result. Workers are essentially off their labor supply curves so equation (1.2) does not hold. In the figure, the co-movement problem is still present, though certainly mitigated. While investment is 0.4% above trend in the first quarter, it falls below trend over the next two years. In quarters two, three and four, investment is below trend by –1.22%, –1.36%, and –1.05% respectively. To resolve the co-movement problem, wages need to be fairly rigid. Figure 7.b shows the same model but with wages set only once every six months on average. The co-movement problem is now significantly reduced. Investment is above trend in the first two quarters (by 1.28% and 0.2% respectively) following the shock and falls below trend only afterwards (in the third and fourth quarters investment is below trend by by –0.28% and –0.44%).

8. Conclusion

Sticky price models exhibit strongly counterfactual behavior when they include markets for durable goods with flexible prices. Consumers care about the *stock* of durable goods rather than the flow of purchases. Because the timing and magnitude of durables purchases can be varied considerably without noticeable changes in the stock, purchases of durable goods have an inherently high intertemporal elasticity of substitution. When the economy expands, marginal costs rise throughout the economy. High marginal costs combined with a readiness to bunch the production and purchase of durables means that

[16] Slightly more generally, if production of durables requires intermediate goods and the prices of these intermediates were sticky then real costs in the durables industry itself may fall after a monetary expansion. Sticky wages are a particular type of sticky intermediate prices.

when the rest of the economy expands, durable goods sectors with flexible prices should contract.

In a special case in which the only sticky prices are those of nondurables, the negative co-movement of durable and nondurable production is exactly offsetting and money is neutral with respect to aggregate output. While the neutrality result requires special circumstances, the perverse response of flexible price durables to monetary policy is robust. We conclude that standard sticky price models require significant additional features to resolve this discrepancy between theory and data.

References:

Ball, Laurence and Romer, David. “Real Rigidities and the Non-Neutrality of Money.” *Review of Economic Studies* 57, April 1990: 183-203.

Basu, Susanto and Fernald, John. “Aggregate Productivity and the Productivity of Aggregates.” *NBER* working paper # 5382, December 1995

Bernanke, Ben S. and Mihov, Ilian. “Measuring Monetary Policy.” *Quarterly Journal of Economics*, 113 (3), August 1998, 869-902.

Bils, Mark and Klenow, Peter. “Some Evidence on the Importance of Sticky Prices.” working paper, January 2002

Blinder, Alan and Mankiw, N. Gregory. “Aggregation and Stabilization Policy in a Multi-Contract Economy”, *Journal of Monetary Economics* 13, January 1984, 67-86

Chari, V.V.; Kehoe, Patrick and McGrattan, Ellen, “Sticky Price Models of the Business Cycle: Can the Contract Multiplier Solve the Persistence Problem?” *Econometrica* 68, no. 5 (September 2000): 1151-1179.

Doyle, Brian and Faust, John. “Three Dummies and the Stock Market.” Working paper, Federal Reserve Board, International Finance Division.

Erceg, Christopher; Henderson, Dale, and Levin, Andrew. “Optimal Monetary Poicy with Staggered Wage and Price Contracts.” *Journal of Monetary Economics*, 46 (2), October 2000, 281-313.

Kimball, Miles, “The Quantitative Analytics of the Basic Neomonetarist Model.” *Journal of Money, Credit, and Banking*, 27(4), 1995 Part 2, 1241-1277.

Leahy, John. “*Comment on* The Effects of Real and Monetary Shocks in a Business Cycle Model with Some Sticky Prices.” *Journal of Money, Credit and Banking*, v 27, n 4, Nov. 1995 part II.

Mankiw, N. Gregory. “Hall's Consumption Hypothesis and Durable Goods.” *Journal of Monetary Economics* 10, Nov. 1982, 417-426.

Murphy, Kevin M.; Shleifer, Andrei and Vishny, Robert . “Building Blocks of Market Clearing Business Cycle Models.” *NBER* Working Paper. June 1989

Ohanian, Lee and Stockman, Alan. “Short-Run Effects of Money when some Prices are Sticky.” Federal Reserve Bank of Richmond *Economic Quarterly*, v 80, n 3, Summer 1994.

Ohanian, Lee; Stockman, Alan and Killian, Lutz. "The Effects of Real and Monetary Shocks in a Business Cycle Model with Some Sticky Prices." *Journal of Money, Credit and Banking*, v 27, n 4, Nov. 1995 part II.

Romer, Christina and Romer David. "Does Monetary Policy Matter? A New Test in the Spirit of Friedman and Schwartz" *NBER* Macroeconomics Annual 4, 1989: 121-170.

Sargent, Thomas, J. *Macroeconomic Theory*, 2nd ed. Academic Press, 1987.

Shapiro, Matthew. "Federal Reserve Policy: Cause and Effect." in *Monetary Policy*, N. G. Mankiw ed. 1994, University of Chicago Press.

Tobin, James. "A Dynamic Aggregative Model." *Journal of Political Economy*, 1955.

Zbaracki, Mark; Ritson, Mark; Levy, Daniel; Dutta, Shantanu and Bergen, Mark. "Managerial and Customer Dimensions of Cost of Changing Prices: Direct Evidence from Industrial Markets." Working paper. 2002.

Appendicies

Appendix A.1: The Benchmark Model.

The following model allows the durable good to function either as a final good or as productive capital. As a result, in the statement of the model, the stock of durables appears in both the production function and the utility function. We focus on the two special cases in which (1) the durable is in only the utility function and (2) the durable is only productive capital. The results are qualitatively unchanged if durable goods function as both productive capital and as a final good.

A.1.1 Households:

The household gets utility from non-durable consumption (C_t) and durable consumption (D_t). The household gets *dis*utility from labor N_t. Their utility function is:

$$\sum_{t=0}^{\infty}\beta^t\left\{\frac{1}{1-\frac{1}{\sigma}}\left[\left(\psi_c C_t^{\theta}+\psi_d D_t^{\theta}\right)^{\frac{1}{\theta}}\right]^{1-\frac{1}{\sigma}}-\phi\frac{N_t^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}}\right\}$$

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

Households earn nominal wages W_t. Their nominal flow budget constraint is:

$$P_t^c C_t+P_t^d X_t+M_t=W_tN_t+M_{t-1}+T_t+R_tD_t$$

P_t^d is the price of new durable goods and X_t is the quantity of new durables purchased at date t. T_t is a (nominal) lump sum transfer which includes taxes, transfers and profits from firms. We allow the household to earn a return on their stock of durables in the case in which the durables function as a production input. In this case, R_t is the nominal rental price of the durable.

The stock of durables obeys:

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

The solution of the households optimization problem implies the following labor supply curve, and Euler equation:

$$v'\left(N_t\right)=\frac{W_t}{P_t^c}MU(C_t)$$

$$MU(C_t)\frac{P_t^x}{P_t^c}=\beta E_t\left[MU(D_{t+1})+(1-\delta)MU(C_{t+1})\frac{P_{t+1}^x}{P_{t+1}^c}\right]$$

Define $U_t=\left(\psi_1C_t^{\theta}+\psi_2D_t^{\theta}\right)^{\frac{1}{\theta}}$ so that $U_t^{\theta}=\psi_1C_t^{\theta}+\psi_2D_t^{\theta}$ then:

$$\phi N_t^{\frac{1}{\eta}}=\frac{W_t}{P_t^c}U_t^{1-\frac{1}{\sigma}-\theta}\psi_cC_t^{\theta-1}$$

$$U_t^{1-\frac{1}{\sigma}-\theta}C_t^{\theta-1}\frac{P_t^x}{P_t^c}=\beta E_t\left[U_{t+1}^{1-\frac{1}{\sigma}-\theta}\left(\frac{\psi_d}{\psi_c}D_{t+1}^{\theta-1}+(1-\delta)C_{t+1}^{\theta-1}\frac{P_{t+1}^x}{P_{t+1}^c}\right)\right]$$

A.1.2: Production and Price Setting

We assume that final goods are produced from a mix of intermediate goods according to a standard Dixit-Stiglitz aggregator.

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

The final goods producers are competitive while the intermediate goods producers are monopolistically competitive. Free entry into the production of the final goods implies that the price of final goods are

$$P_t^d = \left[\int_0^1 p_t^d(s)^{1-\varepsilon} ds\right]^{\frac{1}{1-\varepsilon}}, \; P_t^c = \left[\int_0^1 p_t^c(s)^{1-\varepsilon} ds\right]^{\frac{1}{1-\varepsilon}}$$

The demand for any one intermediate is:

$$x_t(s) = X_t \left(\frac{p_t^d(s)}{P_t^d}\right)^{-\varepsilon}, \; c_t(s) = C_t \left(\frac{p_t^c(s)}{P_t^c}\right)^{-\varepsilon} \tag{1}$$

ε is the price elasticity of demand for any one intermediate good producer s.

Intermediate goods are produced by local monopolists who take the demand curves (1) as given and produce with the Cobb-Douglas technologies

$$x_t(s) = A \left[k_t^x(s)\right]^{\alpha} \left[n_t^x(s)\right]^{1-\alpha}, \; c_t(s) = A \left[k_t^c(s)\right]^{\alpha} \left[n_t^c(s)\right]^{1-\alpha} \tag{2}$$

The monopolists are price takers in capital and labor markets and chooses a mix of capital and labor to minimize production costs. Given R_t and W_t, nominal marginal costs for any one firm are given by:

$$MC_t = A^{-1} W_t^{1-\alpha} R_t^{\alpha} (\alpha - 1)^{\alpha-1} \alpha^{-\alpha} \tag{3}$$

and the optimal capital to labor ratio is:

$$MC_t = \frac{W_t}{A(1-\alpha)} \left(\frac{k_t^j(s)}{n_t^j(s)}\right)^{-\alpha} \tag{4}$$

which is firm s's labor demand curve for $j = c, x$. Since all firms take W_t and R_t as given, they all choose the same capital to labor ratio $\frac{k^x(s)}{n^x(s)} = \frac{k^c(s)}{n^c(s)} = \frac{K}{N}$.

Intermediate goods producers choose $p_t(s)$ to maximize profits. Firms that have sticky prices are modeled using a Calvo price setting mechanism. The probability that a firm will have its price stuck is θ so that $1-\theta$ is the probability that the firm can adjust their price.

The firms maximize the present discounted value of their profits.

$$\max_{p_t^*(s)} \left\{ \sum_{j=0}^{\infty} \theta^j E_t \left[\beta^j \frac{MU(C_{t+j})}{P_{t+j}} \left(p_t^*(s) - MC_{t+j}\right) \left(\left[\frac{p_t^*(s)}{P_{t+j}}\right]^{-\varepsilon} C_{t+j} \right) \right] \right\} \tag{5}$$

Let P_t^* be the optimal reset price (which is the same for all intermediate goods producers s). Then, the price of the final goods is:

$$P_t^c = \left[\theta \left(P_{t-1}^c\right)^{1-\varepsilon} + (1-\theta)\left(P_t^{*,c}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$$

$$P_t^x = \left[\theta \left(P_{t-1}^x\right)^{1-\varepsilon} + (1-\theta)\left(P_t^{*,x}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$$

To a first order approximation this implies that total final goods are given by:[17]

$$C_t = A_t \left(K_t^c\right)^{\alpha} \left(N_t^c\right)^{1-\alpha} \tag{6}$$

$$X_t = A_t \left(K_t^x\right)^{\alpha} \left(N_t^x\right)^{1-\alpha} \tag{7}$$

The model is solved by log-linear approximation using the Anderson-Moore (AIM) algorithm.

A.1.3: Special Cases:

We focus on the following two special cases:

[17] Note that the group of firms selected by the Calvo parameter is a purely random group of firms. With staggered price setting models or in sS models, the firms that adjust have the most outdated prices. In such a case, the "mix" of intermediate goods would be distorted and production would not be exactly Cobb-Douglas.

Case I: Durable goods have a utility service flow but do not function as capital ($\psi_d > 0$ and $\alpha = 0$). In this case, production is linear in labor N_t and there is no capital.

Case II: The durable goods are productive capital but do not have a utility service flow ($\psi_d = 0$ and $0 < \alpha < 1$). In this case, production is a standard Cobb-Douglas function with capital given by the total stock of durables:

$$D_t = K_t$$

A.1.4: Parameterizations.

The benchmark parameter values for the two special cases are:

Benchmark Parameterizations

All		Case 1		Case 2	
Parameter	Value	Parameter	Value	Parameter	Value
β	.98	ϕ	0	ϕ	–
η	1	$\frac{C}{Y}$	.75	ψ_d	0
δ	.1	α	0	α	.35
σ	1				

(β and δ are annual rates; in Case I $\frac{\psi_d}{\psi_c}$ is chosen to give the $\frac{C}{Y}$ ratio).

A.1.5: Wage Setting

We follow Erceg, Henderson and Levin [2000] by modelling wage rigidity as a Calvo sector. Specifically, we assume that effective labor for the firms is an aggregate of labor "types". Specifically, if L_t is effective labor at time t we have:

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

This means that if the firm wants labor force L_t, the demand for type i is given by:

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

Wages for each type of labor are set by a monopolist in that type (similar to a union). The aggregate wage is then:

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

The probability of adjusting a wage is $1 - \theta_w$ and the probability of not adjusting is θ_w. Monopolists seek to maximize:

$$\max_{w_{it}^*} \left\{ E_t \left[\sum_{j=0}^{\infty} (\beta\theta)^j \left(\frac{MU(C_{t+j})}{P_{t+j}} w_{it}^* - MU(N_{t+j})\right) L_{t+j} \left(\frac{w_{it}}{W_{t+j}}\right)^{-\psi}\right]\right\}$$

The steady state wage satisfies:

$$w^* = \frac{\psi}{(\psi-1)} \frac{-MU(N_t)}{\frac{MU(C_t)}{P_t}}$$

so that the real wage is the competitive wage $\frac{-MU(N)}{MU(C)}$ plus a markup.

This implies the following wage setting equation:

$$\tilde{\pi}_t^w = \gamma_w \left[\tilde{P}_t + \frac{1}{\eta}\tilde{N}_t + \frac{1}{\sigma}\tilde{C}_t - \tilde{W}_t\right] + \beta E\left[\tilde{\pi}_{t+1}^w\right]$$

with $\gamma_w = \frac{(1-\theta_w)(1-\theta_w\beta)}{\theta_w}$.

Figure 1.a : Average Response of Real Production Following a Romer Date

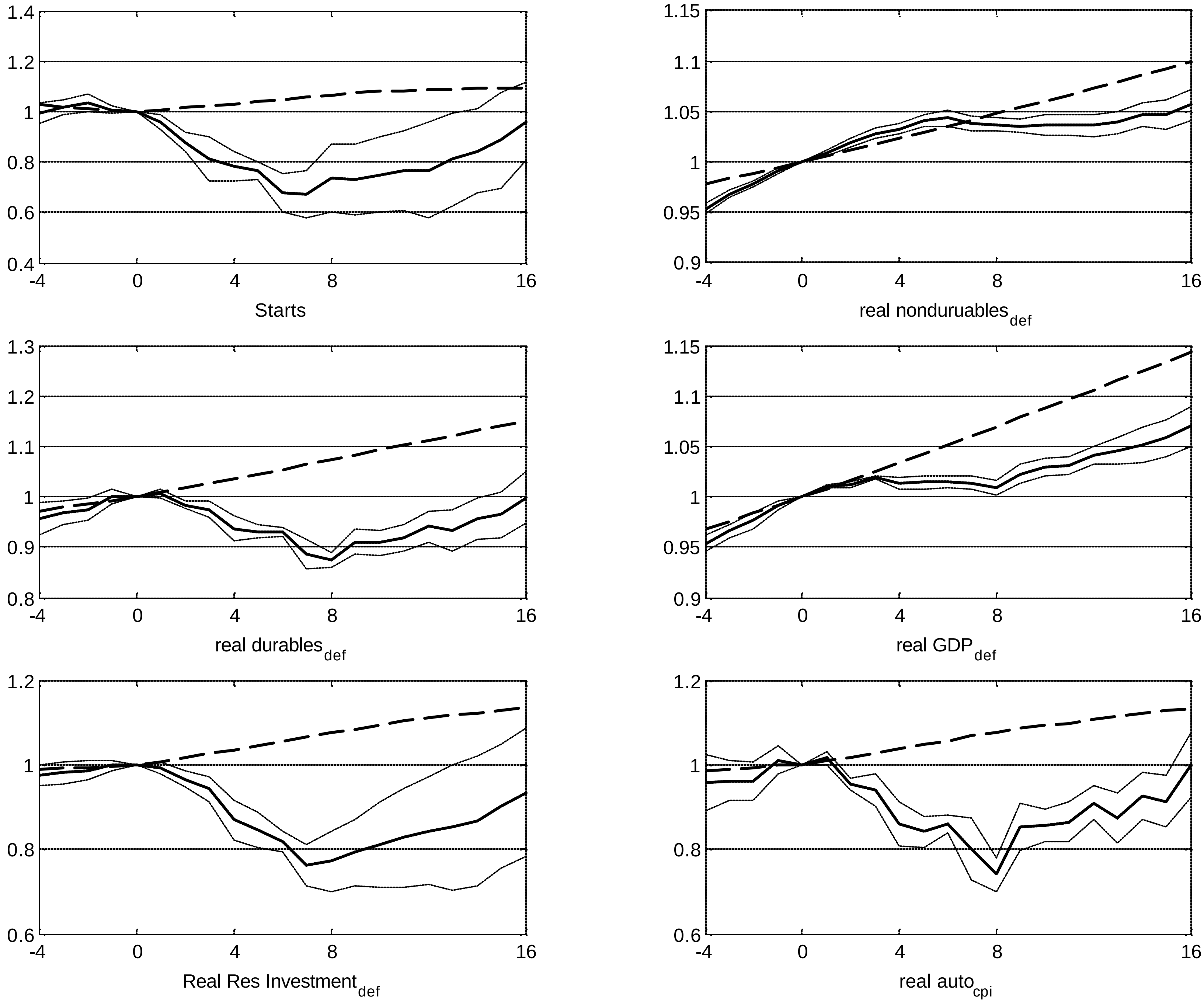


Figure 1.b : Average Response of Relative Prices Following a Romer Date

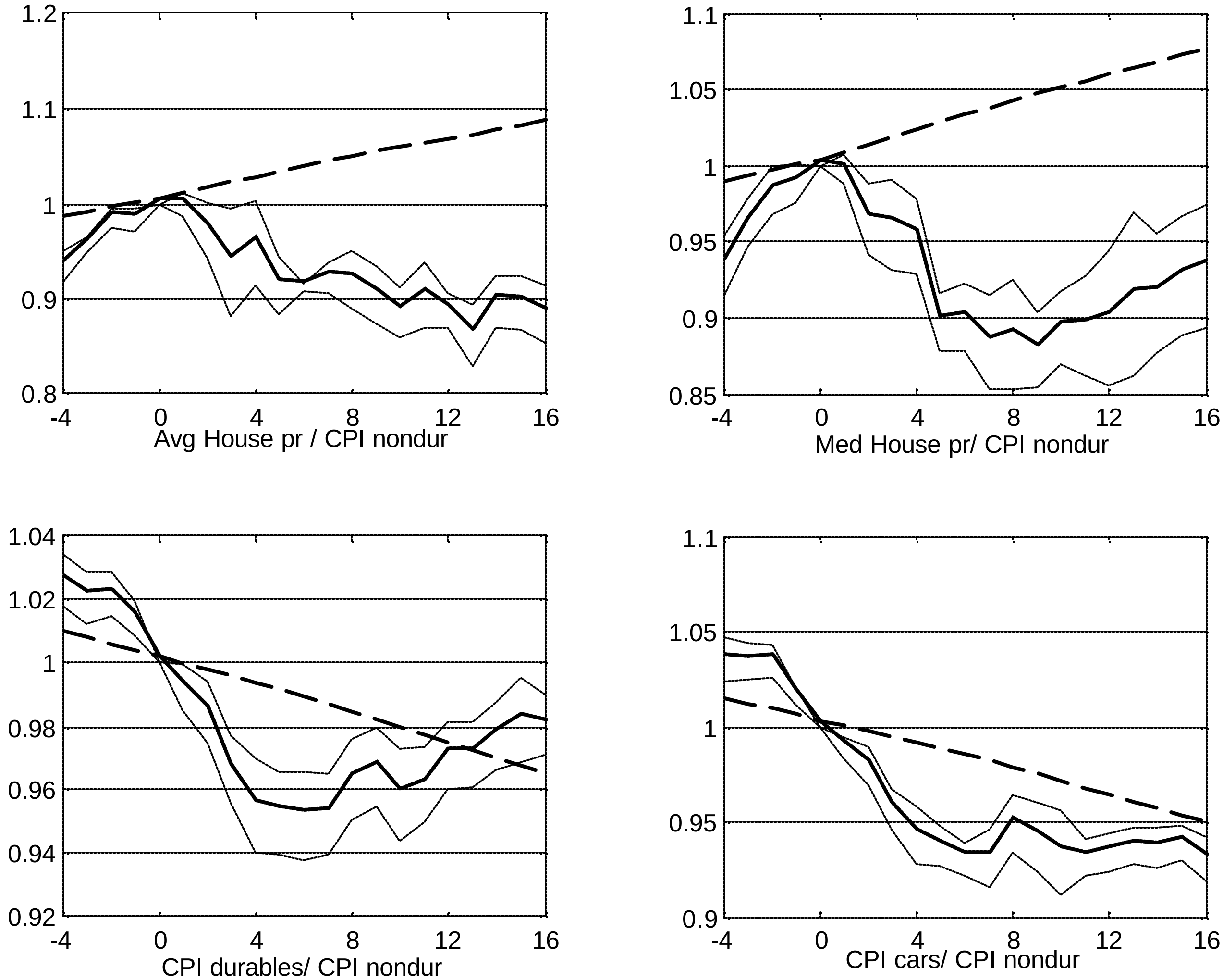


Figure 1.c : Average Response of Variables Following a Romer Date

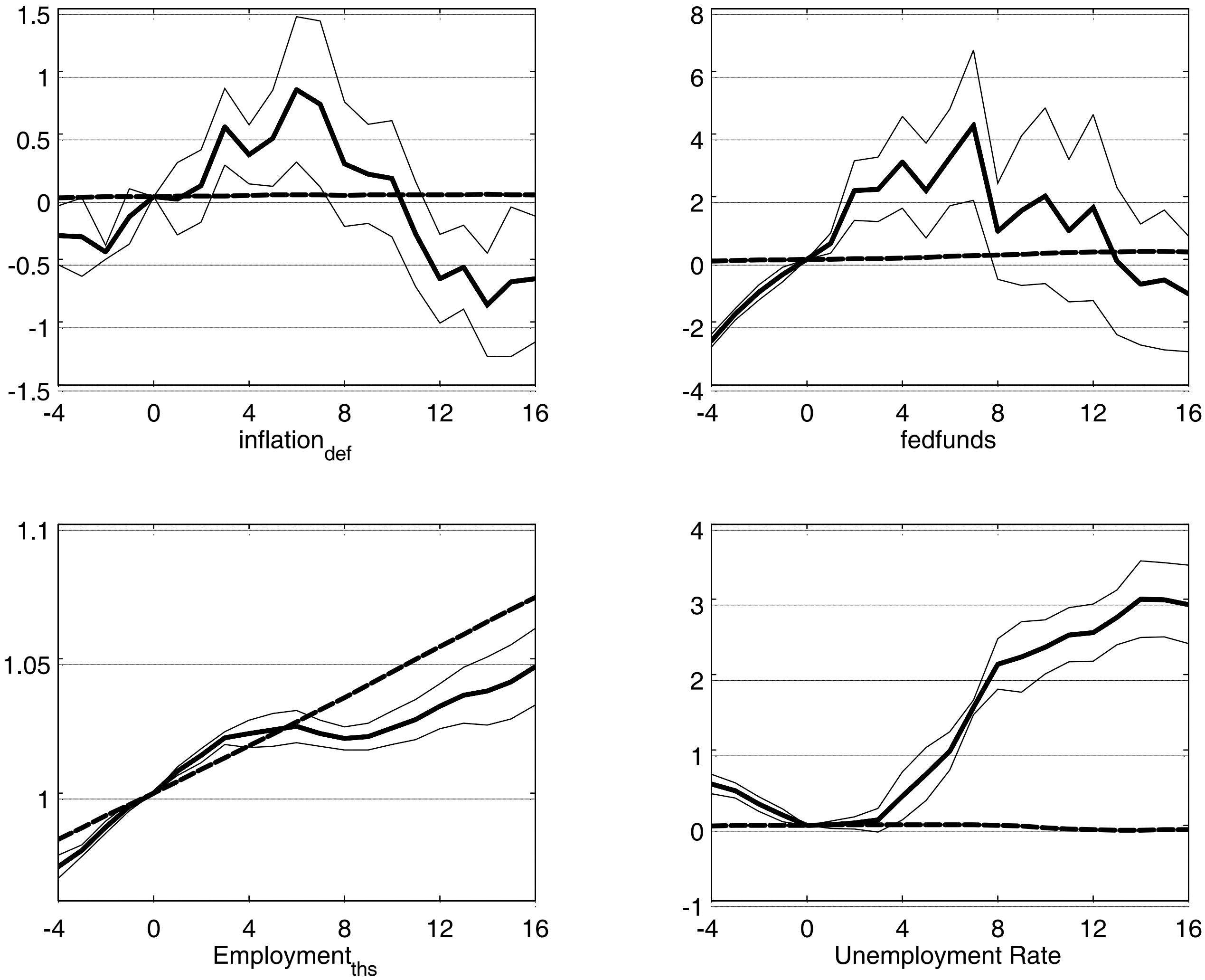
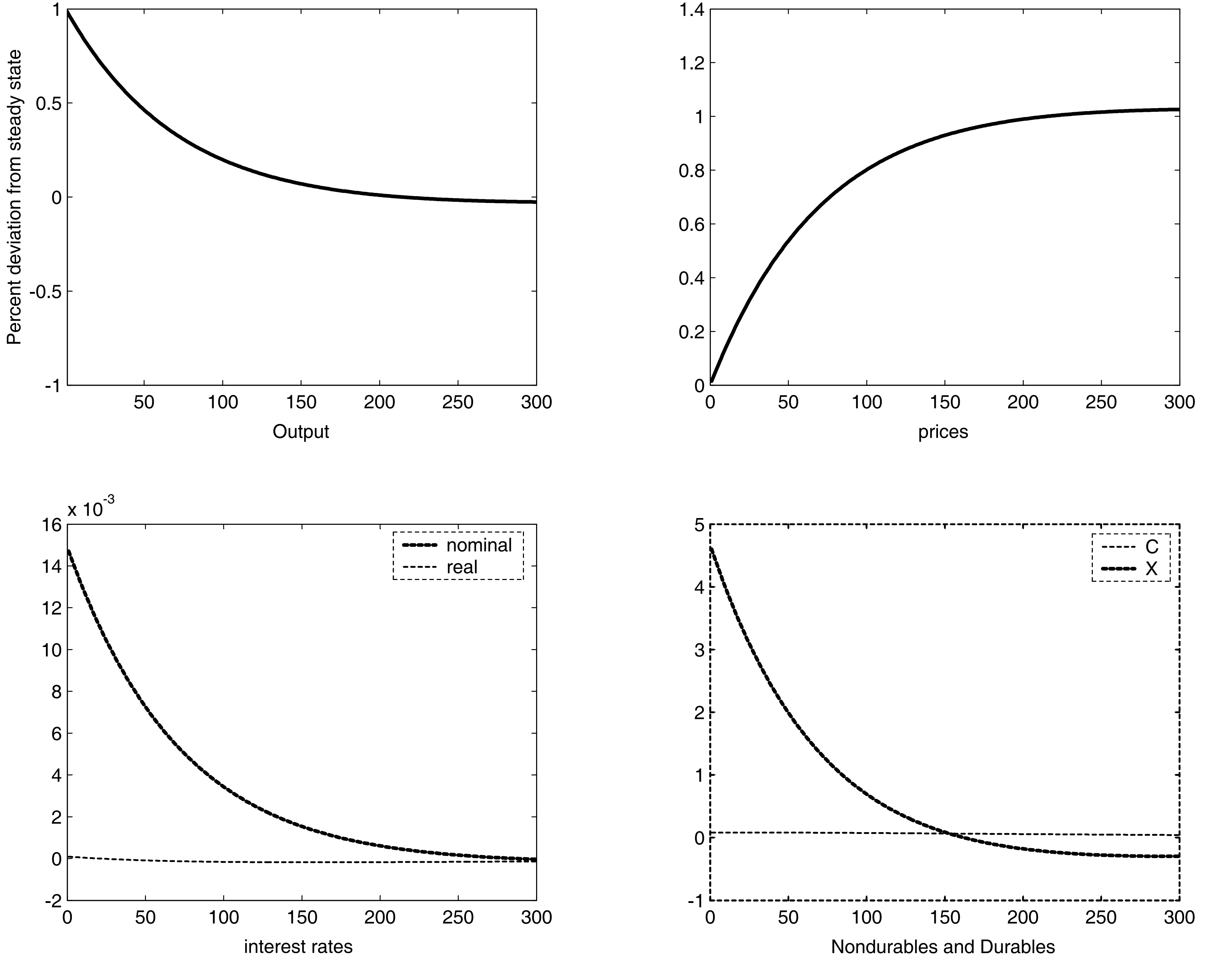


Figure 2



Percent deviation from steady state
1
0.5
0
-0.5
-1
50
100
150
200
250
300
Output
1.4
1.2
1
0.8
0.6
0.4
0.2
0
prices
x 10^-3
16
14
12
10
8
6
4
2
-2
nominal
real
interest rates
5
4
3
2
C
X
Nondurables and Durables

Figure 3: Sticky Nondurables Prices and Flexible Durables Prices

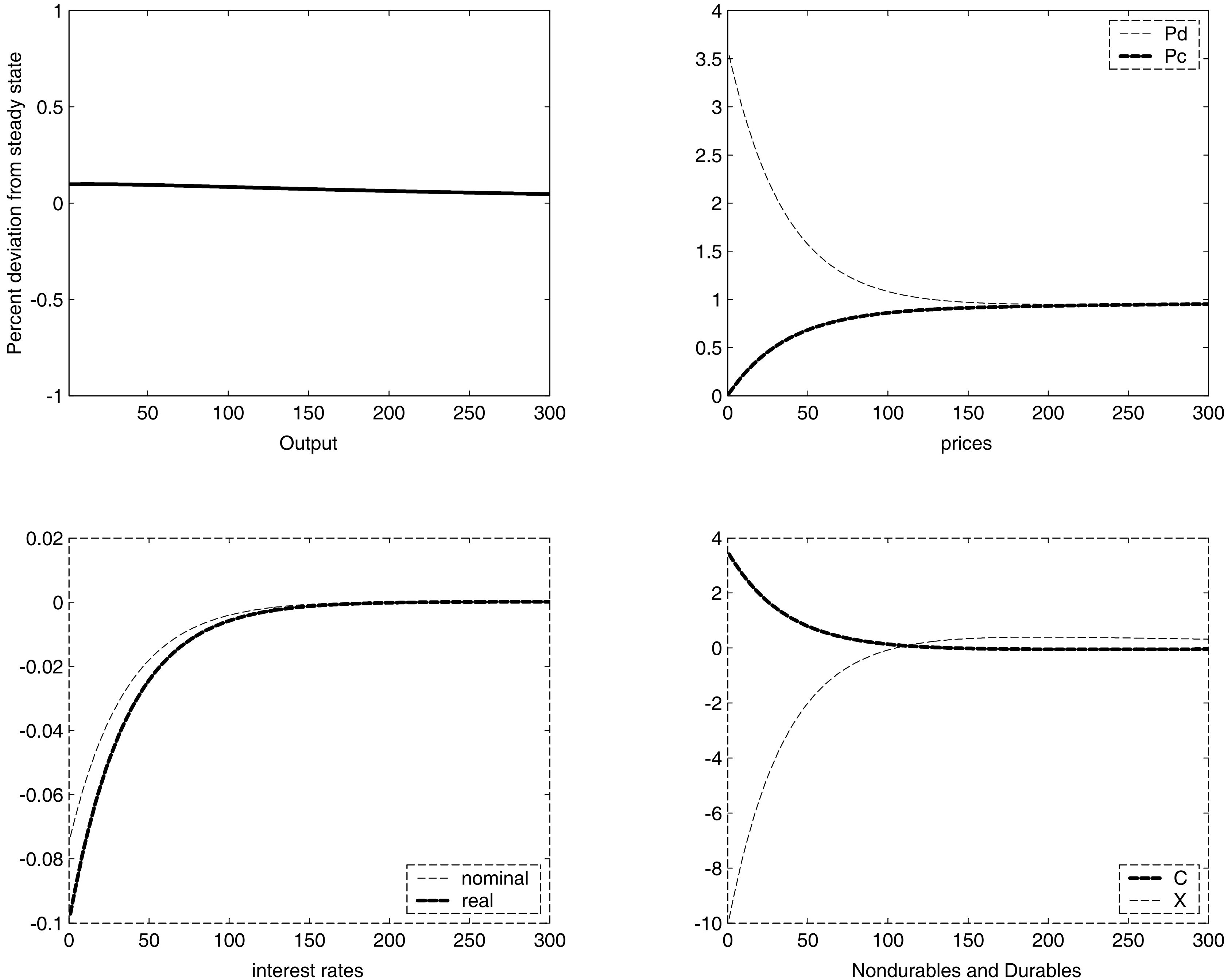


Figure 4: Sticky Durable Good Prices and Flexible Nondurable Prices

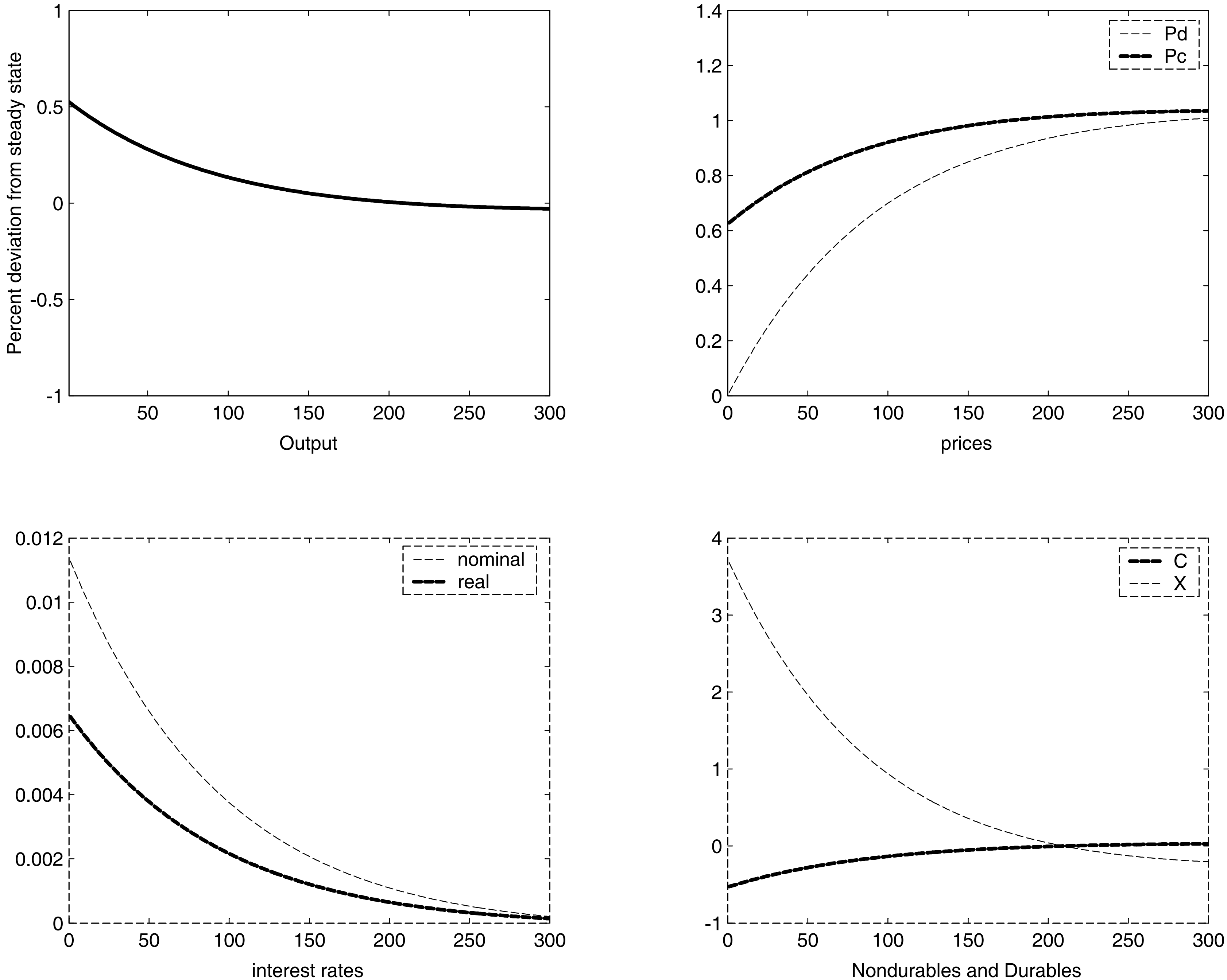


Figure 5: 1st Quarter Output Resposes for Different Models

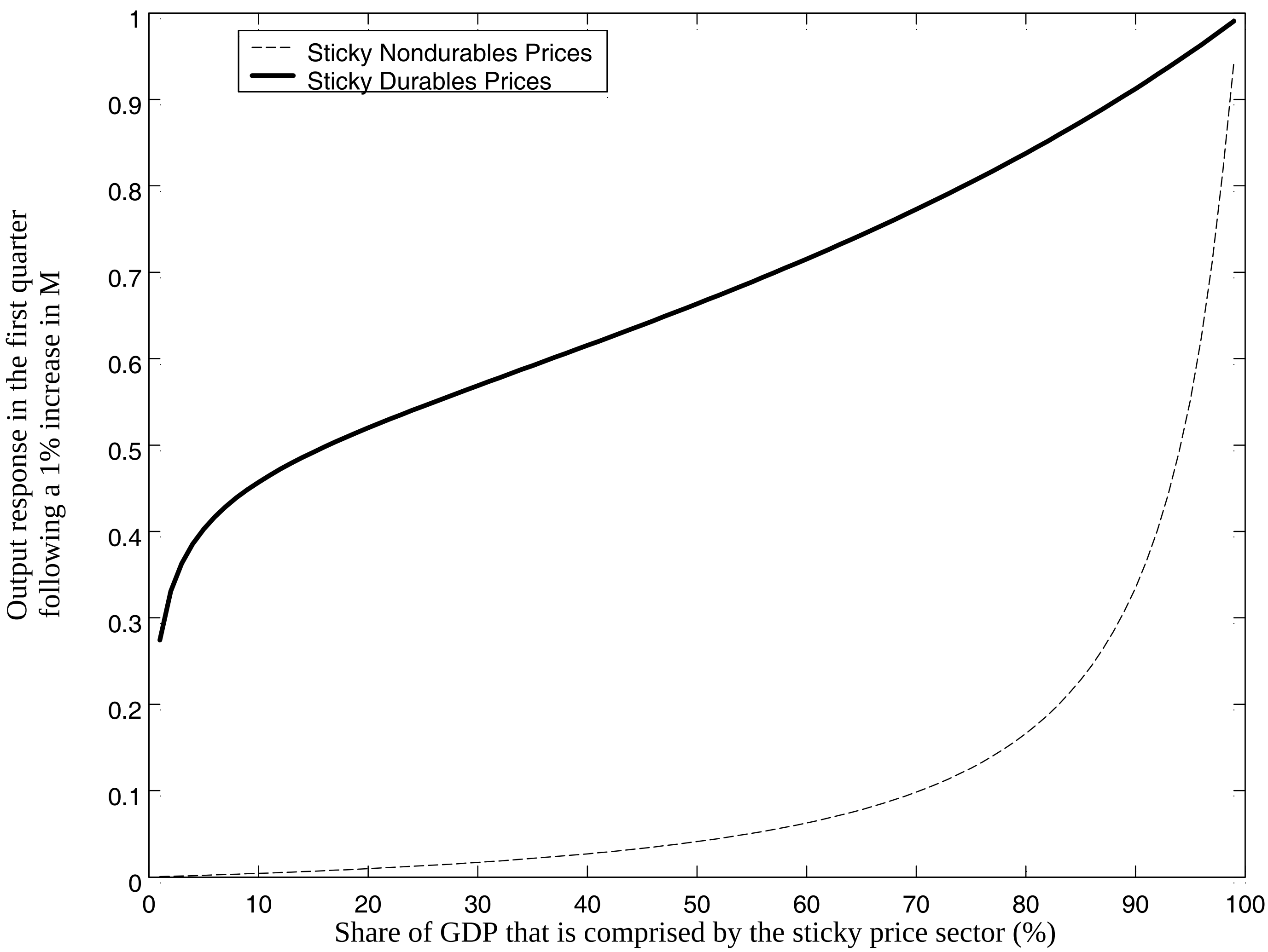


Figure 6 : Complementarity Between Durable and Nondurable Goods

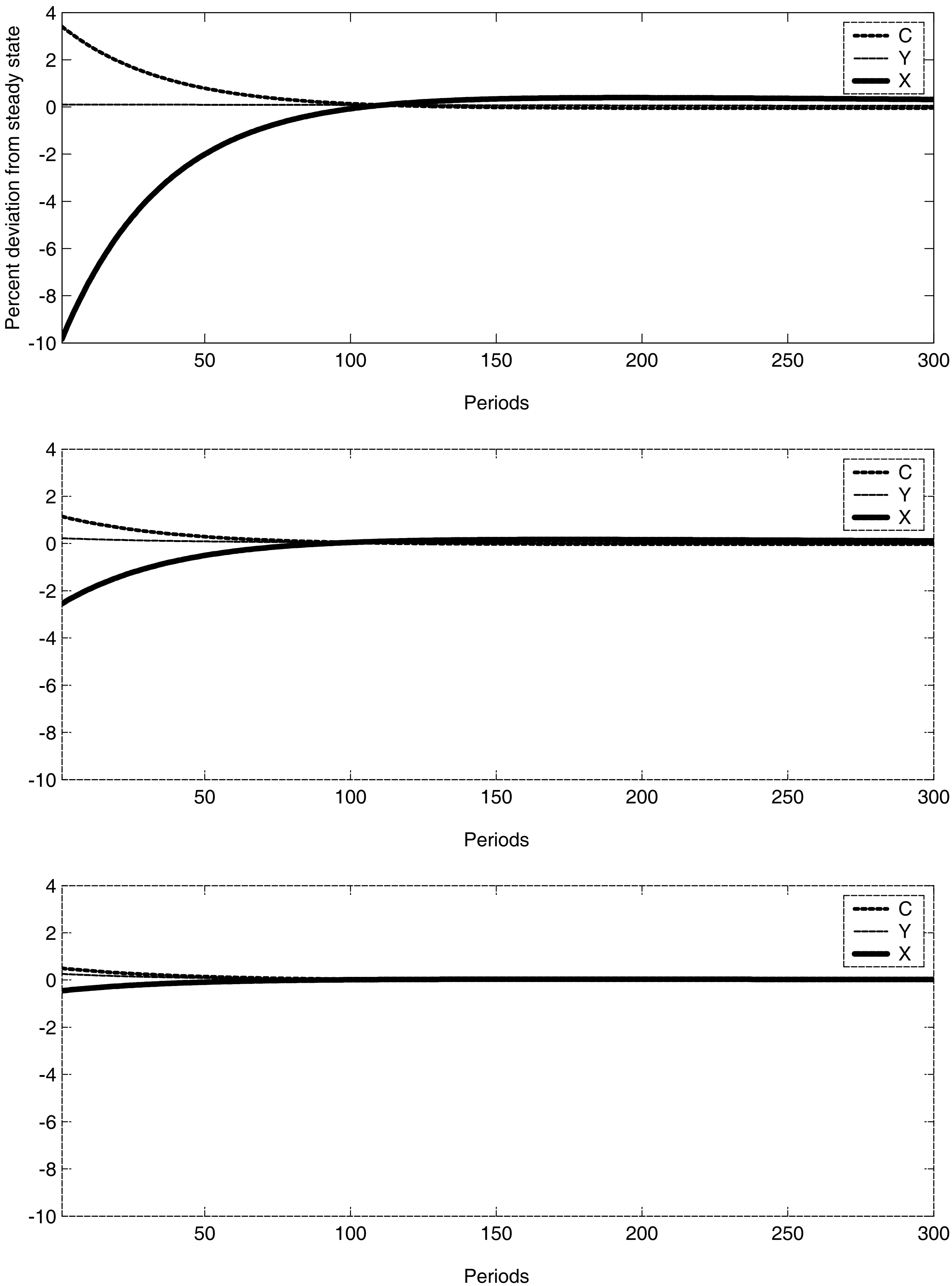


Figure 7.a : Sticky Wages and Flexible Durable Goods Prices

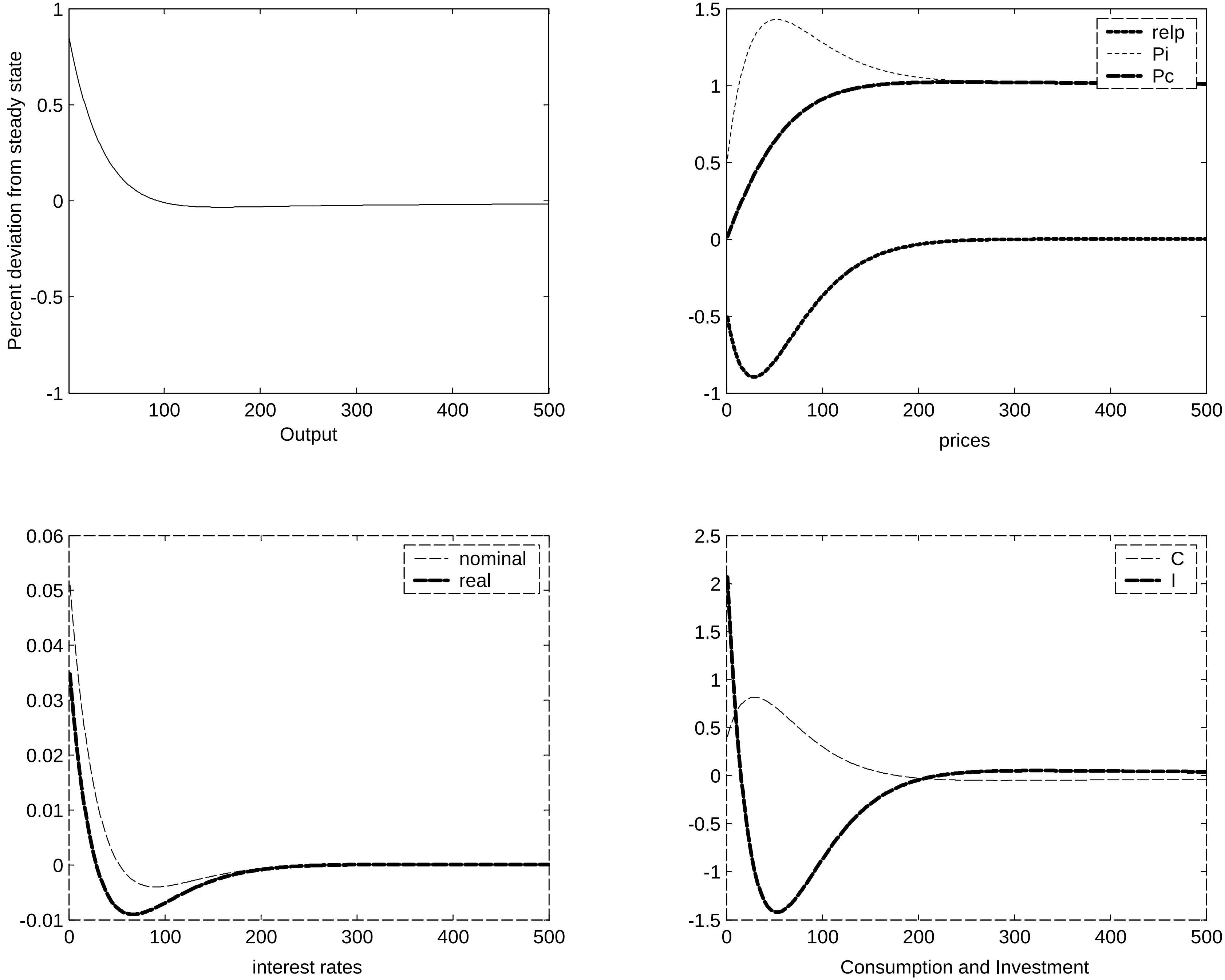


Figure 7.b : Sticky Wages and Flexible Durable Goods Prices