Optimal Monetary Policy with Durable and Non-Durable Goods

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Abstract: We document that the durable goods sector is much more interest-sensitive than the non-durables sector, and then investigate the monetary policy implications of these sectoral differences. We formulate a two-sector general equilibrium model that is calibrated both to match the sectoral responses to a monetary shock derived from our empirical VAR, and to imply an empirically realistic degree of sectoral output volatility and comovement. While the social welfare function involves sector-specific output gaps and inflation rates, the performance of the optimal policy rule can be closely approximated by a simple rule that targets a weighted average of aggregate wage and price inflation. In contrast, rules that stabilize a more narrow measure of final goods price inflation perform poorly in terms of social welfare.

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1 Introduction*

In past decades, macroeconomists were acutely aware of the extent to which the effects of monetary policy differ widely across sectors of the economy.[1] These differences were particularly evident during the U.S. disinflationary episode of 1981-82, when high real interest rates induced dramatic declines in auto sales and residential construction. Nevertheless, recent empirical research has mainly focused on the aggregate effects of monetary policy shocks, while normative studies of policy rules have typically utilized models consisting of a single productive sector.[2]

The objective of this paper is to assess whether taking account of sectoral differences has important implications for the design of welfare-maximizing monetary policy rules. As a prelude to our normative analysis, we document that the durable goods sector is much more interest-sensitive than the non-durables sector. In partic-

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[1]Notable examples include Hamburger 1967; Parks 1974; Mishkin 1976; Mankiw 1985; Gali 1993; Baxter 1996.

[2]For example, Rotemberg and Woodford (1997) consider an economy with a continuum of producers that manufacture differentiated non-durable goods; see also Goodfriend and King (1997), King and Wolman (1999), Erceg et al. (2000); Fuhrer (2000).

ular, we perform vector autoregression (VAR) analysis of quarterly U.S. output and price data, disaggregated into durable and non-durable expenditures. Under fairly standard identifying assumptions, we find that a monetary policy innovation has a peak impact on durable expenditures that is several times as large as its impact on non-durable expenditures.

We proceed to formulate a two-sector dynamic general equilibrium model with both durable and non-durable consumption goods. Our model incorporates nominal price and wage rigidities in each sector so that the monetary policymaker faces a nontrivial stabilization problem. The model is calibrated so that the response of output in each sector to a monetary innovation roughly matches the impulse response function from our estimated VAR. Moreover, using the estimated distribution of shocks to government spending and to the total factor productivity of each sector, the model implies an empirically realistic degree of sectoral output volatility and comovement.

Our model retains enough simplicity to permit a tractable and intuitively appealing representation of the social welfare function. Thus, the quadratic approximation to the welfare function depends on the variances of sectoral output gaps, and on cross-sectional dispersion in wages and prices in each sector. We show that the relative weights in the welfare function depend crucially on the specific structure of overlapping nominal contracts. In particular, the Taylor-style fixed duration contracts used in our analysis (Taylor 1980) imply a much higher *relative* weight on output volatility than the Calvo-style random duration contracts (Calvo 1983) that have been utilized in most previous normative analyses. We obtain the optimal monetary policy rule under full commitment, and characterize its prescriptions in response to government spending and productivity shocks

Finally, we evaluate the performance of simple monetary policy rules that respond only to aggregate variables. We find that strict price inflation targeting generates relatively high volatility in sectoral output gaps (especially in the interest-sensitive sector), and hence performs very poorly in terms of social welfare. Given that the welfare function involves sector-specific variables, one might expect to obtain relatively poor welfare outcomes from any policy rule that responds solely to aggregate variables. In fact, however, we find that policies that keep *aggregate* output near potential come close to the optimal rule by avoiding excessive dispersion in sectoral output gaps and inflation rates (though the optimal rule would smooth variation in durables to a somewhat greater degree). One such policy consists in targeting an appropriately-weighted average of aggregate price and wage inflation, and may be regarded as a generalized form of inflation-targeting in which the underlying basket includes an index of labor costs (Erceg et al, 2000; Mankiw and Reis, 2002). While it generally achieves a similar outcome as a policy rule that directly targets the true aggregate output gap, it does not require knowledge of the level of potential output.

The remainder of this paper is organized as follows: Section 2 presents empirical evidence on sectoral responses to monetary policy shocks. Section 3 outlines the dynamic general equilibrium model, Section 4 describes the solution method and parameter calibration, and Section 5 analyzes the baseline model's properties. The approximation to the social welfare function is derived in Section 6. Section 7 characterizes optimal monetary policy and evaluates the performance of alternative policy rules. Section 8 concludes.

2 Empirical Evidence

A large literature has utilized identified VARs to measure the response of aggregate output and prices to a monetary policy shock (cf. Sims 1980; Christiano, Eichenbaum, and Evans 1999). Here we follow this approach to investigate the extent to which a shock has differential effects on output in the durable and non-durable sectors of the economy.[3] We start by considering five expenditure components of chain-weighted real GDP: consumer durables, residential structures, business equipment, business structures, and all other goods and services. We specify an 8-variable VAR that involves the logarithms of these five variables as well as the logarithm of the GDP price index, the logarithm of the IMF commodity price index, and the level of the federal funds rate. The VAR includes 4 lags of each variable, and is estimated using OLS over the period 1966:1 to 2000:4. Using a Cholesky decomposition (ordering the variables as listed above), we compute the response of these variables to a one-standard-deviation innovation to the federal funds rate. Monte Carlo simulations are used to obtain 95 percent confidence bands for each impulse response function (IRF).

As shown in Figure 1, the IRFs indicate that investment expenditures are much

[3] Recent work by Christiano, Eichenbaum, and Evans (2001) and Angeloni et al. (2002) has investigated the response of aggregate consumption and investment to a monetary policy shock in a just-identified VAR framework. While we allow for a somewhat more disaggregated specification of investment spending , our results appear broadly similar (after weighting the responses of investment components by their expenditure share).

more interest-sensitive than other goods and services. In particular, the monetary policy shock induces an initial rise of about 75 basis points in the federal funds rate; this increase is largely reversed within the next several quarters. Spending on other goods and services exhibits a maximum decline of about 0.2 percent in response to this shock; given that this component accounts for about three-quarters of nominal GDP, it is not too surprising that the magnitude of this response is roughly similar to that obtained for total GDP in a typical 4-variable VAR. In contrast, the maximum response is 5-10 times larger for consumer durables and residential investment, and 2-3 times larger for business structures and equipment. It is also interesting to note the differences in timing of the maximum decline, which occurs within the first year for consumer durables and residential investment, but takes about twice as long for business equipment and structures.

In the subsequent analysis, we will formulate a two-sector model that abstracts from endogenous capital accumulation and focuses on the behavior of durable expenditures that contribute directly to household utility. To analyze the empirical analogues of these two components of aggregate output, we disaggregate real GDP into only two types of expenditures: a chain-weighted index of consumer durables and residential investment, and a chain-weighted composite of all other expenditures (including business fixed investment).[4] Since our analytic work will consider sector-specific price dynamics, we also construct a chain-weighted price index for each type of expenditure. We proceed to estimate a 6-variable VAR involving the two expen-

[4]We construct these chain-weighted sectoral measures using the Tornqvist approximation discussed by Whelan (2000).

diture variables and the corresponding price indices as well as the IMF commodity price index and the federal funds rate. We compute IRFs using this ordering for the variables in the Cholesky decomposition, and then construct bootstrapped confidence intervals via Monte Carlo simulations.

As shown in Figure 2A, the composite of consumer durables and residential investment spending exhibits a maximum decline of about 1.4 percent, compared with about 0.2 percent for all other GDP expenditure components. The price decline in each sector is much more gradual than the output decline, suggesting the importance of short-run nominal inertia.[5]

Figure 2B shows impulse responses derived from a VAR with an identical structure, except that is estimated over a shorter sample (1980:1-2000:4) It is apparent that the responses from the subsample are smaller and less persistent than those derived from the full sample, perhaps reflecting changes in the structure of the economy, or in the form of the monetary policy rule. However, the maximum response of the expenditure components to a *given-sized* monetary innovation is quite similar across the overlapping sample periods. Using estimates from both sample periods, an 80 basis point rise in the federal funds rate induces a contraction in the composite of durables/residential investment of roughly 1-1.4 percent, and a contraction in other GDP components that is only about one-quarter as large (with the longer sample suggesting a even smaller relative response). As shown below, we calibrate the parameters of the model to roughly match the magnitude of these responses to a

[5] Interestingly, there is little evidence of a "price puzzle" in the responses of the sectoral price indexes.

monetary innovation.

3 The Model

Our model consists of two sectors that produce distinct types of output, namely, durable and non-durable consumption goods. Labor and product markets in each sector exhibit monopolistic competition, and sectoral wages and prices are determined by staggered four-quarter nominal contracts. Each sector has a fixed capital stock. Each household has two types of workers that are permanently tied to their respective productive sectors. Household preferences are separable both in the consumption of the two goods and in work effort supplied to the two sectors. As shown below, these assumptions enable us to obtain a relatively simple expression for social welfare that can decomposed into distinct components corresponding to each of the two sectors.

3.1 Firms and Price Setting

Henceforth we use the subscript m to refer to the sector that produces durable goods ("manufacturing"), while the subscript s refers to the sector that produces non-durables ("services"). Within each sector, a continuum of monopolistically competitive firms (indexed on the unit interval) fabricate differentiated products $Y_{jt}(f)$ for $j \in \{m, s\}$ and $f \in [0, 1]$. Because households have identical Dixit-Stiglitz preferences, it is convenient to assume that a representative aggregator combines the differentiated products of each sector into a single sectoral output index Y_{jt}:

$$Y_{jt} = \left[\int_0^1 Y_{jt}(f)^{\frac{1}{1+\theta_{pj}}} \, df \right]^{1+\theta_{pj}} \tag{1}$$

where $\theta_{pj} > 0$. The aggregator chooses the bundle of goods that minimizes the cost of fabricating a given quantity of the sectoral output index Y_{jt}, taking the price $P_{jt}(f)$ of each good $Y_{jt}(f)$ as given. The aggregator sells units of each sectoral output index at its unit cost P_{jt}:

$$P_{jt} = \left[\int_0^1 P_{jt}(f)^{\frac{-1}{\theta_{pj}}} \, df \right]^{-\theta_{pj}} \tag{2}$$

It is natural to interpret P_{jt} as the sectoral price index. The aggregate price index P_t (also referred to as the GDP price deflator) is simply defined as:

$$P_t = P_{mt}^{\psi_m} P_{st}^{1-\psi_m} \tag{3}$$

where ψ_m is the steady state output share of the manufacturing sector.

The aggregator's demand for each good $Y_{jt}(f)$–or equivalently total household demand for this good – is given by

$$Y_{jt}(f) = \left[\frac{P_{jt}(f)}{P_{jt}} \right]^{\frac{-(1+\theta_{pj})}{\theta_{pj}}} Y_{jt} \tag{4}$$

for $j \in \{m, s\}$ and $f \in [0, 1]$.

Each differentiated good is produced by a single firm that hires capital services $K_{jt}(f)$ and a labor index $L_{jt}(f)$ defined below. All firms within each sector face the same Cobb-Douglas production function, with an identical level of total factor productivity A_{jt}:

$$Y_{jt}(f) = A_{jt} K_{jt}(f)^{\alpha_j} L_{jt}(f)^{1-\alpha_j} \tag{5}$$

Capital and labor are perfectly mobile across the firms within each sector, but cannot be moved between sectors. Furthermore, each sector's total capital stock is fixed at $\bar{K}_j$. Each firm chooses $K_{jt}(f)$ and $L_{jt}(f)$, taking as given the sectoral rental price of capital P^k_{jt} and the sectoral wage index W_{jt} defined below. The standard static first-order conditions for cost minimization imply that all firms within each sector have identical marginal costs per unit of output (MC_{jt}), which can be expressed as a function of the sectoral labor index L_{jt}, as well as the sectoral wage index, capital stock, and total factor productivity:

$$MC_{jt} = \frac{W_{jt} L_{jt}^{\alpha_j}}{(1-\alpha_j) A_{jt} \bar{K}_j^{\alpha_j}} \tag{6}$$

Note that real marginal cost (deflated by the sectoral price index) can be equivalently expressed as the ratio of the sectoral real wage to the marginal product of labor:

$$\frac{MC_{jt}}{P_{jt}} = \frac{\frac{W_{jt}}{P_{jt}}}{MPL_{jt}} \tag{7}$$

$$MPL_{jt} = (1-\alpha_j) A_{jt} \bar{K}^{\alpha_j} L_{jt}^{-\alpha_j} \tag{8}$$

We assume that the prices of intermediate goods are determined by staggered nominal contracts of fixed duration (as in Taylor, 1980). Each price contract lasts four quarters, and one-fourth of the firms in each sector reset their prices in a given period. Thus, individual producers may be indexed so that every firm with index $f \in [0, 0.25]$ resets its contract price $P_{jt}(f)$ whenever the date is evenly divisible by 4; similarly, firms with index $f \in [0.25, 0.5]$ set prices during periods in which mod(t,4)

=1, and so forth. Whenever the firm is not allowed to reset its contract, the firm's price is automatically increased at the unconditional mean rate of gross inflation, Π. Thus, if firm f in sector j has not adjusted its contract price since period t, then its price i periods later is given by $P_{j,t+i}(f) = P_{jt}(f)\,\Pi^i$.

When a firm is allowed to reset its price in period t, the firm maximizes the following profit functional with respect to its contract price, $P_{jt}(f)$:

$$\mathcal{E}_t \sum_{i=0}^{3} \psi_{t,t+i}((1+\tau_{pj})\Pi^i P_{jt}(f)\, Y_{j,t+i}(f) - MC_{j,t+i} Y_{j,t+i}(f)) \tag{9}$$

The operator $\mathcal{E}_t$ represents the conditional expectation based on information through period t. The firm's output is subsidized at a fixed rate τ_{pj}. The firm discounts profits received at date $t+i$ by the state-contingent discount factor $\psi_{t,t+i}$; for notational simplicity, we have suppressed all of the state indices from this expression. Let $\gamma_{t,t+i}$ denote the price in period t of a claim that pays one dollar if the specified state occurs in period $t+i$; then the corresponding element of $\psi_{t,t+i}$ is given by $\gamma_{t,t+i}$ divided by the probability that the specified state will occur.

By differentiating this profit functional with respect to $P_{jt}(f)$, we obtain the following first-order condition:

$$\mathcal{E}_t \sum_{i=0}^{3} \psi_{t,t+i} \left[(1+\tau_{pj})\Pi^i P_{jt}(f) - (1+\theta_{pj})\, MC_{j,t+i}\right] Y_{j,t+i}(f) = 0 \tag{10}$$

Thus, the firm sets its price so that the sum of its expected discounted nominal revenue (inclusive of subsidies) is equal to the price markup factor $(1+\theta_{pj})$ multiplied by the sum of discounted nominal costs. We assume that production is subsidized to eliminate the monopolistic distortion in each sector; that is, $\tau_{pj} = \theta_{pj}$ for $j \in \{m, s\}$. Thus, in the steady state of the model, prices are equated to marginal cost in each sector, or equivalently, the sectoral marginal product of labor is equal to the sectoral real wage, as in a perfectly competitive economy.

3.2 Households and Wage Setting

We assume that a continuum of households is indexed on the unit interval, and each household supplies differentiated labor services. Within every household, a fixed number of members ν_m work exclusively in the manufacturing sector, while the remaining ν_s members work exclusively in the service sector. Each member of a given household $h \in [0,1]$ who works in a given sector $j \in \{m, s\}$ has the same wage rate $W_{jt}(h)$ and supplies the same number of hours $N_{jt}(h)$. As in the firm's problem described above, it is convenient to assume that a representative labor aggregator (or "employment agency") combines individual labor hours into a sectoral labor index L_{jt} using the same proportions that firms would choose:

$$L_{jt} = \nu_j \left[\int_0^1 N_{jt}(h)^{\frac{1}{1+\theta_{wj}}} dh \right]^{1+\theta_{wj}} \tag{11}$$

where $\theta_{wj} > 0$. The aggregator minimizes the cost of producing a given amount of the aggregate labor index, taking the wage rate $W_{jt}(h)$ for each household member as given, and then sells units of the labor index to the production sector at unit cost W_{jt}:

$$W_{jt} = \left[\int_0^1 W_{jt}(h)^{\frac{-1}{\theta_{wj}}} dh \right]^{-\theta_{wj}} \tag{12}$$

It is natural to interpret W_{jt} as the sectoral wage index. The aggregator's demand for the labor hours of household h – or equivalently, the total demand for this household's labor by all goods-producing firms – is given by

$$\nu_j N_{jt}(h) = \left[\frac{W_{jt}(h)}{W_{jt}}\right]^{-\frac{1+\theta_{wj}}{\theta_{wj}}} L_{jt} \tag{13}$$

In each period, the household purchases $Y_{mt}(h)$ units of durable goods at price P_{mt}, and $C_t(h)$ units of non-durable goods (or services) at price P_{st}. To generate a source of demand for money, we assume that non-durables must be purchased using cash balances, while durable goods can be purchased using credit. The household's stock of durable goods $D_t(h)$ evolves as follows:

$$D_{t+1}(h) = (1-\delta) D_t(h) + Y_{mt}(h) \tag{14}$$

where the depreciation rate δ satisfies the condition $0 < \delta \leq 1$.

The household's expected lifetime utility is given by

$$\mathcal{E}_t \sum_{i=0}^{\infty} \beta^i \mathbb{W}_{t+i}(h) \tag{15}$$

The operator $\mathcal{E}_t$ here represents the conditional expectation over all states of nature, and the discount factor β satisfies $0 < \beta < 1$. The period utility function $\mathbb{W}_t(h)$ is additively separable with respect to the household's durables stock $D_t(h)$, its consumption of non-durables $C_t(h)$, the leisure of each household member, and the household's nominal money balances $M_t(h)$ deflated by the price index of non-durables P_{st}:

$$\mathbb{W}_t(h) = \mathbb{U}\left(\check{D}_t(h)\right) + \mathbb{S}(C_t(h)) + \mathbb{V}(N_{mt}(h)) + \mathbb{Z}(N_{st}(h)) + \mathbb{M}\left(\frac{M_t(h)}{P_{st}}\right) \tag{16}$$

In particular, the household receives period utility $\mathbb{U}(\widetilde{D}_t\,(h)\,)$ from its current durables stock net of adjustment costs, $\widetilde{D}_t\,(h)$:

$$\mathbb{U}\left(\widetilde{D}_t\,(h)\right) = \frac{\sigma_{m_0}\left[\widetilde{D}_t\,(h)\right]^{1-\sigma_m}}{1-\sigma_m} \tag{17}$$

where

$$\widetilde{D}_t\,(h) = D_t\,(h) - 0.5\phi\frac{(Y_{mt}\,(h) - \delta D_t\,(h))^2}{D_t\,(h)} \tag{18}$$

and the parameters $\sigma_{m_0} > 0$, $\sigma_m > 0$ and $\phi \geq 0$. The remaining components of period utility are given as follows:

$$\mathbb{S}\,(C_t\,(h)) = \frac{[C_t\,(h)]^{1-\sigma_s}}{1-\sigma_s} \tag{19}$$

$$\mathbb{V}\,(N_{mt}\,(h)) = v_m\frac{[1-N_{mt}\,(h)]^{1-\chi_m}}{1-\chi_m} \tag{20}$$

$$\mathbb{Z}\,(N_{st}\,(h)) = v_s\frac{[1-N_{st}\,(h)]^{1-\chi_s}}{1-\chi_s} \tag{21}$$

$$\mathbb{M}\left(\frac{M_t\,(h)}{P_{st}}\right) = \frac{\mu_0}{1-\mu}\left(\frac{M_t\,(h)}{P_{st}}\right)^{1-\mu} \tag{22}$$

where the parameters σ_s, χ_m, χ_s, μ, and μ_0 are all strictly positive. We will utilize $\mathbb{U}'_t\,(h)$ to denote the derivative of $\mathbb{U}\left(\widetilde{D}_t\,(h)\right)$ with respect to $\widetilde{D}_t\,(h)$, along with similar notation for the derivatives of each of the other components of the household's period utility.

Household h's budget constraint in period t states that consumption expenditures plus asset accumulation must equal disposable income:

$$P_{mt}Y_{mt}(h) + P_{st}C_t(h)$$

$$+M_{t+1}(h) - M_t(h) + \int \gamma_{t,t+1}B_{t+1}(h) - B_t(h) \tag{23}$$

$$= \nu_m(1+\tau_{wm})W_{mt}(h)\,N_{mt}(h) + \nu_s(1+\tau_{ws})W_{st}(h)\,N_{st}(h)$$

$$+\Gamma_{mt}(h) + \Gamma_{st}(h) - T_t(h)$$

Financial asset accumulation consists of increases in money holdings and the net acquisition of state-contingent claims. As noted above, $\gamma_{t,t+1}$ represents the price of an asset that will pay one unit of currency in a particular state of nature in the subsequent period, while $B_{t+1}(h)$ represents the quantity of such claims purchased by the household at time t. Total expenditure on new state-contingent claims is given by integrating over all states at time $t+1$, while $B_t(h)$ indicates the value of the household's existing claims given the realized state of nature. Disposable income consists of the sum of wage income (which is subsidized at a fixed rate τ_{wj} in each sector) and an aliquot share $\Gamma_{jt}(h)$ of each sector's profits and rental income, minus a lump-sum tax $T_t(h)$ that is paid to the government.[6]

[6] The sum of sectoral profits and rental income accruing to each household ($\Gamma_{jt}(h)$) are determined by the following identity:

$$\int_0^1 \Gamma_{jt}(h)\,dh = \int_0^1 [(1+\tau_j)P_{jt}(f)\,Y_{jt}(f) - W_{jt}L_{jt}(f)]df$$

Nominal wage rates are determined by staggered fixed duration contracts, under assumptions symmetric to those stated earlier for price contracts. In particular, the duration of the wage contract of each household member is four quarters. Whenever the household is not allowed to reset the wage contract, the wage rate is automatically increased at the unconditional mean rate of gross inflation, Π. Thus, if the wage contract of the household member has not been adjusted since period t, then the wage rate i periods later is given by $W_{j,t+i}(h) = W_{jt}(h)\Pi^i$.

In every period t, each household h maximizes its expected lifetime utility with respect to its consumption of services, purchases of durables, holdings of money, and its holdings of contingent claims: subject to the demand for its labor in each sector, equation (13), and its budget constraint, equation (23).

The first-order conditions for consumption of non-durables and holdings of state-contingent claims imply the familiar "consumption Euler equation" linking the marginal cost of foregoing a unit of consumption of non-durables in the current period to the expected marginal benefit in the following period:

$$\mathbb{S}'_t = \mathcal{E}_t\left[\beta(1+R_{st})\,\mathbb{S}'_{t+1}\right] = \mathcal{E}_t\left[\beta(1+I_t)\frac{P_{st}}{P_{st+1}}\mathbb{S}'_{t+1}\right] \tag{24}$$

where the risk-free real interest rate R_{st} is the rate of return on an asset that pays one unit of non-durables consumption under every state of nature at time $t+1$, and the nominal interest rate I_t is the rate of return on an asset that pays one unit of currency under every state of nature at time $t+1$. Note that the omission of the household-specific index in equation (24) reflects our assumption of complete contingent claims markets for consumption (although not for leisure), so that each type of consumption is identical across all households in every period; that is, $C_t = C_t(h)$, $Y_{mt} = Y_{mt}(h)$, and $D_t = D_t(h)$ for all $h \in [0, 1]$.

The first-order condition for durable goods expenditures can be expressed as

$$Q_t \mathbb{S}_t' = \mathcal{E}_t \left[\beta(1-\delta_d) Q_{t+1} \mathbb{S}_{t+1}' + \beta(1 + \phi \tfrac{\Delta D_{t+2}}{D_{t+1}} + \tfrac{\phi}{2} \tfrac{\Delta D_{t+2}^2}{D_{t+1}^2}) \mathbb{U}_{t+1}' - \phi \tfrac{\Delta D_{t+1}}{D_t} \mathbb{U}_t' \right] \tag{25}$$

where Q_t denotes the relative price ratio P_{mt}/P_{st}.

In any period t in which the household is able to reset the wage contract for its members working in the manufacturing sector, the household maximizes its expected lifetime utility with respect to the new contract wage rate $W_{mt}(h)$, yielding the following first-order condition:

$$\mathcal{E}_t \sum_{i=0}^{3} \beta^i \left((1+\tau_{wm}) \frac{\Pi^i W_{mt}(h)}{P_{m,\,t+i}} Q_{t+i} \mathbb{S}_{t+i}' + (1+\theta_{wm}) \mathbb{V}_{t+i}'(h) \right) N_{m,t+i}(h) = 0 \tag{26}$$

Similarly, in any period t in which the household is able to reset the wage contract for its members working in the service sector, the household maximizes its expected lifetime utility with respect to $W_{st}(h)$, yielding the following first-order condition:

$$\mathcal{E}_t \sum_{i=0}^{3} \beta^i \left((1+\tau_{ws}) \frac{\Pi^i W_{st}(h)}{P_{s,t+i}} \mathbb{S}_{t+i}' + (1+\theta_{ws}) \mathbb{Z}_{t+i}'(h) N_{s,t+i}(h) \right) = 0 \tag{27}$$

We assume that employment is subsidized to eliminate the monopolistic distortion in each sector; that is, $\tau_{wj} = \theta_{wj}$ for $j \in \{m, s\}$. Thus, the steady state of the model satisfies the efficiency condition that the marginal rate of substitution in each sector equals the real wage, as in a perfectly competitive economy.

3.3 Fiscal and Monetary Policy

The government's budget is balanced every period, so that total lump-sum taxes plus seignorage revenue are equal to output and labor subsidies plus the cost of government purchases:

$$M_t - M_{t-1} + \int_0^1 T_t(h)\,dh = \int_0^1 \tau_m P_{mt}(f)\,Y_{mt}(f)\,df + \int_0^1 \tau_s P_{st}(f)\,Y_{st}(f)\,df$$
$$+ \int_0^1 \tau_{wm} W_{mt}(h)\,N_{mt}(h)\,dh + \int_0^1 \tau_{ws} W_{st}(h)\,N_{st}(h)\,dh + P_{st}G_t \tag{28}$$

where G_t indicates real government purchases from the service sector. Finally, the total output of the service sector is subject to the following resource constraint:

$$Y_{st} = C_t + G_t \tag{29}$$

We assume that the short-term nominal interest rate is used as the instrument of monetary policy, and that the policymaker is able to commit to a time-invariant rule. We consider alternative specifications of the monetary policy rule in our analysis, including both rules that can be regarded as reasonable characterizations of recent historical experience, and rules derived from maximizing a social welfare function.

4 Solution and Calibration

To analyze the behavior of the model, we log-linearize the model's equations around the non-stochastic steady state. Nominal variables, such as the contract price and wage, are rendered stationary by suitable transformations. We then compute the reduced-form solution of the model for a given set of parameters using the numerical algorithm of Anderson and Moore (1985), which provides an efficient implementation of the solution method proposed by Blanchard and Kahn (1980).

4.1 Parameters of Private Sector Behavioral Equations

The model is calibrated at a quarterly frequency. Thus, we assume that the discount factor $\beta = .993$, consistent with a steady-state annualized real interest rate $\overline{r}$ of about 3 percent. We assume that the preference parameters $\sigma_m = \sigma_s = 2$, implying that preferences over both durables and non-durables exhibit a somewhat lower intertemporal substitution elasticity than the logarithmic case; these settings for the preference parameters are well within the range typically estimated in the empirical literature. The leisure preference parameters $\chi_m = \chi_s = 3$.[7] The capital share parameters $\alpha_m = \alpha_s = 0.3$. The quarterly depreciation rate of the durables stock $\delta = 0.025$, implying an annual depreciation rate of 10 percent. This choice reflects that the durables sector in our model includes both consumer durables and residential investment, which have annual depreciation rates of about 20 percent and 3 percent, respectively, and that the expenditure share of consumer durables in the composite is about two-thirds. The sectoral price and wage markup parameters $\theta_{Ps} = \theta_{Ws} = \theta_{Pm} = \theta_{Wm} = 0.3$. As noted above, price and wage contracts in each

[7] We scale the level of capital to hours worked in each sector so that the ratio of hours worked to leisure (denoted ℓ_j below) equals 1/2 in the steady state in each sector. We choose the scaling parameter in the subutility function for durables σ_{m0} so that the relative price of durables in terms of non-durables is equal to unity in the steady state.

sector are specified to last four quarters. The share of the durables sector in both output and employment ψ_m is set equal to 0.125, implying that the share of services $\psi_s = 0.875$ (this determines the employment size parameters ν_s and ν_m in the subutility functions for leisure). The share of government spending in non-durables production (S_G^s) is set to 0.18, implying that the government share of total output is about 16 percent. Finally, as described below, we set the cost of adjusting the stock of durables parameter $\phi = 600$ in order to match the magnitude of the response of durable goods output to a monetary innovation.

4.2 Monetary Policy Rule

In our baseline specification, we assume that the central bank adjusts the short-term nominal interest rate in response to the four-quarter average inflation rate and to the current and lagged output gaps:

$$i_t = \gamma_i i_{t-1} + \gamma_\pi \pi_t^{(4)} + \gamma_{y,1} g_t + \gamma_{y,2} g_{t-1} + e_t \tag{30}$$

where the four-quarter average inflation rate $\pi_t^{(4)} = \frac{1}{4}\sum_{j=0}^{3} \pi_{t-j}$, g_t is the aggregate output gap, and e_t is a monetary policy innovation; note that constant terms involving the inflation target and steady-state real interest rate are suppressed for simplicity. Orphanides and Wieland (1998) found that this specification provides a good in-sample fit over the 1980:1-1996:4 sample period, and obtained the following parameter estimates: $\gamma_i = 0.795$, $\gamma_\pi = 0.625$, $\gamma_{y,1} = 1.17$, $\gamma_{y,2} = -0.97$, and $std(e_t) = 0.0035$.

4.3 Evolution of Real Shocks

In addition to the monetary policy innovation, our model includes three exogenous stochastic variables: total factor productivity in the production of durables (A_{mt}), total factor productivity in non-durables (A_{st}), and government spending on non-durables (G_t).

These three exogenous variables are assumed to follow a trivariate first-order VAR:

$$\begin{bmatrix} A_{mt} \\ A_{st} \\ G_t \end{bmatrix} = \begin{bmatrix} \rho_m & 0 & 0 \\ 0 & \rho_s & 0 \\ 0 & 0 & \rho_G \end{bmatrix} \begin{bmatrix} A_{mt-1} \\ A_{st-1} \\ G_{t-1} \end{bmatrix} + \begin{bmatrix} e_{mt} \\ e_{st} \\ e_{Gt} \end{bmatrix} \tag{31}$$

where the innovations are assumed to be i.i.d. with contemporaneous covariance matrix . While we allow for innovations to sectoral productivity to be correlated contemporaneously, government spending innovations and monetary innovations are assumed to be uncorrelated both with each other, and with the innovations to productivity. Accordingly, we estimate a univariate first-order autoregression for government spending over the 1980:1-2000:4 sample period (the shorter sample period used in our VAR estimation in Section 2), and find that $\rho_G = 0.92$, and $std(e_{Gt}) = .031$.[8] Next, we estimate the parameters of the bivariate technology shock process using the method of moments. In particular, we choose the five parameters determining the persistence, variance, and covariance of the technology shocks so that our model's implications for the standard deviation of sectoral outputs, their first

[8] We measure government spending as the nonwage component of government consumption spending.

order autocorrelation, and their contemporaneous correlation are exactly consistent with the corresponding sample moments. Our moment-matching procedure takes as given the other structural parameters of our model, including the standard deviation of the monetary innovation, and the estimated process for government spending. In estimating the sample moments, we employ the same data utilized in estimating the VAR associated with Figure 2B.[9] Our procedure yields estimates of $\rho_s = .87$, $\rho_m = .90$, $std(e_{st}) = .0096$, $std(e_{mt}) = .0360$, and $corr(e_{mt}, e_{st}) = .29$.

5 Properties of the Baseline Model

We begin by illustrating the responses of our baseline model to innovations to monetary policy, productivity in each sector, and to government spending. In the cases of the nonmonetary shocks, we compare the baseline model with sticky prices and wages to the alternative case in which wages and prices are fully flexible. Given that household preferences are separable both in the consumption of the two goods and work effort supplied to the two sectors, sector-specific shocks would have no effect on output in the other sector if prices and wages were fully flexible. By contrast, we show that in our baseline model with sluggish price adjustment, sector-specific shocks may have pronounced effects on the other sector. Moreover, we highlight

[9] Thus, "durables" is measured as a chain-weighted composite of consumer durables and residential investment, "nondurables" as other expenditure components of GDP, and the sample period is 1980:1-2000:4. After removing a log-linear trend, we found the quarterly standard deviation of nondurables to be 1.61 percent, of durables 8.69 percent, the autocorrelation of nondurables 0.88, of durables 0.92, and the contemporaneous correlation 0.40.

the channels through which shocks to non-durables may induce large fluctuations in durables.

The impulse responses to a monetary policy shock are shown in Figure 3. The policy shock induces an initial rise in the short-term nominal interest rate (the measure of the policy rate in our model) of about 80 basis points, generating a fall in non-durables output of around 0.3 percentage point. The magnitude of the response of non-durables is close to the maximum response implied in the empirical VARs shown in Figures 2A and 2B (after scaling the policy shock to be 80 basis points in each case). Given the high sensitivity of the user cost of durables to the interest rate, the output of the durables sector is much more responsive to the interest rate change. The parameter ϕ determining the cost of adjusting the stock of durables is calibrated to match the expenditure-weighted average response of consumer durables and residential investment derived from the empirical VARs, which suggests that the maximum response of durables is roughly four times as large as that of non-durables.

Figure 4 compares impulse responses to a one standard deviation innovation to (total factor) productivity in non-durables in the baseline model to the case in which prices and wages are fully flexible. The shock causes a persistent rise in productivity in non-durables, but is sector-specific, and hence has no effect on productivity in the durables sector.[10] Turning first to the case of fully flexible prices (and wages),

[10]The impulse response is a one standard deviation innovation to the orthogonalized residual obtained from a Cholesky factorization of the correlated innovations e_{mt} and e_{st}. Since durables are ordered first, the innovation to non-durables has no spillover effect to productivity in durables. In the case of the durables innovation, there is a small spillover effect to productivity in non-durables.

the shock induces an immediate rise in non-durables output. As can be seen from the log-linearized first order condition for durables, the rise in consumption of the non-durable good (c_t) would raise the demand for durables (d_{t+1}) if the user cost of durables (z_t) remained constant:

$$d_{t+1} = c_t - \frac{1}{\sigma_m} z_t + \phi \mathcal{E}_t \left[\Delta d_{t+2} - (1/\beta) \Delta d_{t+1} \right]$$

$$z_t = q_t + (\tfrac{1-\delta}{r+\delta}) \mathcal{E}_t \left[r_{st} - \Delta q_{t+1} \right] \tag{32}$$

However, because the durables sector is "insulated" from the shock in the flexible price (and wage) equilibrium, the user cost of durables simply rises enough so that the desired stock of durables remains unchanged. This increase in the user cost occurs through a rise in the asset price (q_t), and through the expectation of a future capital loss on holding the durable (so that $\Delta q_{t+1} < 0$).

This sharp initial relative price adjustment (apparent in Figure 4) is a hallmark feature of the flexible price equilibrium: relative price adjustment completely retards the increase in the demand for the stock of durables that would occur if relative prices remained constant. By contrast, with sticky prices in both the durable and non-durable goods sectors, there is a much smaller initial increase in the relative price of durables, and the price of durables is expected to rise for several quarters rather than fall. As a result, there is a much smaller increase in the user cost than when prices are flexible. Consequently, the equilibrium demand condition for durables is satisfied through an increase in the desired stock, and corresponding jump in the production of durables.

It is important to recognize that the presence of price rigidities in both sectors makes monetary policy unable to achieve the flexible price equilibrium. Attainment of the flexible price equilibrium would require both setting the real interest rate on non-durables (which falls in the case of this shock) and the path of the relative price of durables equal to their values under flexible prices; but this is infeasible given the assumed nature of price rigidities.

Figure 5 displays impulse responses to a one standard deviation innovation to productivity in durables. The shock causes a persistent rise in productivity in durables, as well as a small rise in productivity in non-durables that is attributable to the small degree of correlation between the (nonorthogonalized) productivity innovations. In the case of fully flexible prices and wages, the persistent supply shock to durables would at first depress the relative price of durables. The combination of a low relative price and expected capital gain would induce a relatively large increase in the desired stock of durables (and hence a rise in production). By contrast, the relative price declines initially by less if prices are sticky, and there is an expected capital loss associated with owning durables. As a result, the user cost falls by less than under flexible prices, and this generates a much smaller initial output rise.

Finally, Figure 6 depicts impulse responses to a persistent rise in government spending in the non-durables sector. Under flexible prices, the rise in government spending would induce an outward shift in labor supply in the non-durables sector due to a negative wealth effect (since government consumption is assumed to be wasted). While the output of non-durables rises (as shown), non-durables consumption contracts, which acts as negative demand shock to the demand for durables. Because this sector-specific shock has no effect on the durables sector under full flexibility, equilibrium must be achieved solely through a fall in the user cost. Although a rise in the real interest rate on non-durables (r_{st}) has the partial effect of increasing the user cost, this effect is more than offset by a sharp fall in the relative price of durables (q_t), and through the expectation of a future capital gain ($\Delta q_{t+1} > 0$).

By contrast, in our baseline model with sticky prices, producers of new durable goods adjust their prices downward much more slowly than under flexible prices. As a result, the user cost of durables falls by less than under flexible prices. This induces a decline in the desired stock of durables, and contraction in production that is about twice as large as the rise in production in non-durables.

It is clear from these comparisons that the inclusion of sticky prices has important consequences for equilibrium output responses in each sector. Sluggish relative price adjustment causes sector-specific shocks to affect output in the other sector. Moreover, given that the damped adjustment of relative prices changes both the asset price and expected capital gain component of the user cost, sticky price adjustment may induce a high degree of output volatility in the durable goods sector even in response to shocks that would leave it unaffected in the flexible price equilibrium.

6 The Welfare Function

To provide a normative assessment of alternative monetary policy choices, we measure social welfare as the unconditional expectation of average household welfare:

$$SW = \mathcal{E} \int_0^1 \left[\mathcal{E}_t \sum_{i=0}^{\infty} \beta^i \, \mathbb{W}_{t+i}(h) \right] dh \tag{33}$$

For this purpose, it is useful to decompose period utility $\mathbb{W}_t(h)$ as follows:

$$\mathbb{W}_t(h) = \mathbb{W}_t^s(h) + \mathbb{W}_t^m(h) + \mathbb{M}(\tfrac{M_t(h)}{P_{st}})$$

$$\mathbb{W}_t^S(h) = \mathbb{S}(C_t(h)) + \mathbb{Z}(N_{st}(h)) \tag{34}$$

$$\mathbb{W}_t^m(h) = \mathbb{U}(\widetilde{D}_t(h)) + \mathbb{V}(N_{mt}(h))$$

where $\mathbb{W}_t^S(h)$ indicates the household's period utility associated with non-durables consumption and service-sector employment, while $\mathbb{W}_t^m(h)$ denotes the period utility associated with durables consumption and manufacturing employment. In the subsequent analysis, we assume that the welfare losses of fluctuations in real money balances can be safely neglected; that is, μ_0 in equation (22) is arbitrarily small. Then we follow the seminal analysis of Rotemberg and Woodford (1997) in deriving the second-order approximation to each component of the social welfare function and computing its deviation from the welfare of the Pareto-optimal equilibrium under flexible wages and prices. Finally, we express each component of welfare in terms of the equivalent amount of steady-state output.

6.1 Non-durables Component of Social Welfare

The non-durables component of social welfare depends (inversely) on the variance of the output gap in non-durables, and on cross-sectional dispersion in prices and wages (as shown by Erceg et al, 2000). Given that there are effectively only four cohorts of households and firms (differentiated by the period in which they recontract), the unconditional expectation of the non-durables components of social welfare can be expressed as:

$$\left(\tfrac{1-\beta}{Y\,\mathbb{S}_C}\right)\mathcal{E}\sum_{i=0}^{\infty}\beta^i\left(\mathbb{W}^s_{t+i}-\mathbb{W}^{s\,*}_{t+i}\right)\approx-\tfrac{1}{2}\psi_s\left(\mu^s_{mrs}+\mu^s_{mpl}\right)\mathcal{V}ar\left(\hat{Y}_{st}-\hat{Y}^*_{st}\right)$$

$$-\tfrac{1}{8}\psi_s\eta_{ps}\sum_{j=0}^{3}\mathcal{V}ar\ln\left(\tilde{P}_{s,t-j}\,/\,P_{st}\right) \tag{35}$$

$$-\tfrac{1}{8}\psi_s\eta_{ws}\left(1-\alpha_s\right)\left(1+\eta_{ws}\chi_s\ell_s\right)\sum_{j=0}^{3}\mathcal{V}ar\ln\left(\tilde{W}_{s,t-j}\,/\,W_{st}\right)$$

where an asterisk denotes the Pareto-optimal value of the specified variable, a hat denotes the logarithmic deviation from steady state, and $\mathcal{V}ar(\cdot)$ denotes the unconditional variance. Furthermore, $\tilde{P}_{s,t-j}$ indicates the contract price signed by firms at period $t-j$, while $\tilde{W}_{s,t-j}$ indicates the contract wage signed by households at period $t-j$ (for $j=0,...,3$). The welfare loss is expressed as a ratio of the steady state output level.[11]

Our assumption of fixed-duration ("Taylor-style") contracts has important impli-

[11] We use the following notation in our representation of the welfare function: $\eta_{pj}=\frac{1+\theta_{p\,j}}{\theta_{p\,j}}$, $\eta_{wj}=\frac{1+\theta_{w\,j}}{\theta_{w\,j}}$, for $j\in\{m,s\}$, and $\mu^s_{mrs}+\mu^s_{mpl}=(\sigma_s\frac{1-\alpha_s}{1-S^s_G}+\alpha_s+\chi_s\ell_s)/(1-\alpha_s)$ for the non-durables sector. The sum $\mu^s_{mrs}+\mu^s_{mpl}$ may be interpreted as the sum of the absolute values of the slopes of the marginal rate of substitution and the marginal product of labor schedules in non-durables with respect to output.

cations for the welfare costs of inflation volatility.[12] Under the alternative, commonly-used assumption of random-duration ("Calvo-style") contracts, some contracts remain unchanged over long stretches of time, even if the average contract duration is relatively short. Thus under random-duration contracts, fluctuations in aggregate inflation tend to have highly persistent effects on cross-sectional dispersion, and hence the welfare cost of wage and price inflation volatility are at least an order of magnitude greater than the welfare cost of output gap volatility (cf. Rotemberg and Woodford 1997; Erceg et al. 2000). In contrast, fixed-duration contracts induce much less intrinsic persistence of cross-sectional dispersion, and hence imply that the welfare cost of relative price and wage dispersion is roughly comparable in magnitude to the costs of output gap volatility. For example, using our baseline calibration with Taylor-style contracts, the weights on the relative price and wage dispersion terms in the non-durables component of the welfare function (equation (35)) are 0.86 and 4.54, respectively, when expressed as a ratio to the weight on the output gap term. By contrast, using the same calibration except with Calvo-style contracts (with a mean duration of four quarters), the relative weights are 10.4 and 54.5, respectively.

6.2 Durables Component of Social Welfare

Now consider the component of welfare that depends on durables consumption and employment. Taking a second-order approximation to this component of welfare for

[12] Under fixed-duration contracts, the welfare costs of cross-sectional dispersion cannot be summarized solely in terms of the variances of wage and price inflation, but must be given explicitly in terms of the variances of relative wages and prices.

a given household h yields the following expression:

$$\mathcal{E}_t \sum_{i=0}^{\infty} \beta^i \mathbb{W}^m_{t+i}(h) \;\approx\; \mathcal{E}_t \sum_{i=0}^{\infty} \beta^i \Big(DU_D\, \hat{D}_{t+i}$$

$$+\; \tfrac{1}{2}(DU_D + D^2 U_{DD})\hat{D}^2_{t+i} - \tfrac{1}{2}\phi DU_D(\hat{D}_{t+i+1} - \hat{D}_{t+i})^2 \tag{36}$$

$$+\; N_m V_{N_m}\; \hat{N}_{m,t+i}(h) + \tfrac{1}{2} N_m^2 V_{N_m N_m}\; \hat{N}^{\,2}_{m,t+i}(h) \Big)$$

where the absence of a time subscript denotes the steady-state value of the specified variable. Next, take a second-order approximation of equation (14), which describes the evolution of the durables stock:

$$\hat{D}_t \;\approx (1-\delta)\,\hat{D}_{t-1} \;+ \delta \hat{Y}_{m,t-1} + \frac{\delta\,(1-\delta)}{2}\left(\hat{Y}_{m,t-1} - \hat{D}_{t-1}\right)^2. \tag{37}$$

Substituting this formula into the previous equation, taking unconditional expectations, and aggregating across households, we obtain the following expression for the durables component of social welfare:

$$\frac{1-\beta}{Y\mathbb{S}_C}\mathcal{E}\ \sum_{i=0}^{\infty}\beta^i\ \left(\mathbb{W}^m_{t+i}-\mathbb{W}^{m\,*}_{t+i}\right)\approx-\frac{1}{2}\psi_m(1+\chi_s\ell_s)/(1-\alpha_s)\mathcal{V}ar\left(\hat{Y}_{mt}-\hat{Y}^*_{mt}\right)$$

$$-\psi_m(1+\chi_s\ell_s)\mathcal{C}ov\left(\hat{Y}_{mt}-\hat{Y}^*_{mt},\ \hat{L}^*_{mt}\right)$$

$$+\psi_m(1-\sigma_d)\frac{(1-\beta(1-\delta))}{\delta\beta}\left[\mathcal{V}ar(\hat{D}_t)-\mathcal{V}ar(\hat{D}^*_t)\right]$$

$$+\frac{1}{2}\psi_m(1-\delta)\left[\mathcal{V}ar\left(\hat{Y}_{mt}-\hat{D}_t\right)-\mathcal{V}ar\left(\hat{Y}^*_t-\hat{D}^*_t\right)\right] \tag{38}$$

$$-\frac{\phi}{2}\psi_m\frac{(1-\beta(1-\delta))}{\delta\beta}\left[\mathcal{V}ar(\hat{D}_{t+1}-\hat{D}_t)-\mathcal{V}ar(\hat{D}^*_{t+1}-\hat{D}^*_t)\right]$$

$$-\frac{1}{8}\psi_m\eta_{pm}\sum_{j=0}^{3}\mathcal{V}ar\ln\left(\tilde{P}_{m,t-j}\,/\,P_{mt}\right)$$

$$-\frac{1}{8}\psi_m\eta_{wm}\left(1-\alpha_m\right)\left(1+\eta_{wm}\chi_m\ell_m\right)\sum_{j=0}^{3}\mathcal{V}ar\ln\left(\tilde{W}_{m,t-j}\,/\,W_{mt}\right)$$

Thus, just as with the non-durables component, the welfare associated with durables consumption and employment depends on the volatility of the sectoral output gap and on the variability of relative wages and prices. In this case, however, welfare involves some additional terms that arise due to the durability of output and to the quadratic costs of adjusting the stock of durable goods (these terms make only a small contribution to the welfare losses reported below).

7 Monetary Policy Rules

In this section, we compare the performance of alternative simple monetary policy rules in which the interest rate only responds to aggregate variables with the performance of the optimal rule under full commitment.

7.1 Dynamic Responses

Figure 7 shows the effects of a one standard deviation innovation to productivity in non-durables under several alternative monetary policies. These include the case of strict aggregate GDP price inflation targeting, strict aggregate output gap targeting, and the optimal rule under full commitment (which maximizes the social welfare function in equation (33)). In addition, we consider the case of a hybrid targeting rule that responds to a weighted average of aggregate price and wage inflation, where the weights reflect the relative weight on the price and wage dispersion terms in the social welfare function.[13]

It is clear that the optimal rule implies a smaller expansion of the output gap in durables than the alternative policy of aggregate output gap stabilization (where output gap is defined as the difference between output and the level that would

[13] Each of the rules is implemented as a targeting rule, rather than as an instrument rule. In particular, the rule is derived by maximizing a welfare function consistent with the objective in each case subject to the behavioral constraints of the model. In the case of the wage-price targeting rule, we use an objective function with a weight of unity on aggregate price inflation, and of 5.25 on aggregate wage inflation, equal to the relative weight on the price and wage dispersion terms in the social welfare function.

prevail under flexible prices and wages). The latter policy does not take account of the fact that social welfare function depends on the squared output gap in each sector. Hence, while the output gap in durables widens by roughly seven times as much as the output gap in non-durables (in absolute value terms) under aggregate output gap targeting, it only expands about twice as much under the optimal rule. Implementing the optimal rule requires a much sharper initial rise in real interest rates, and is consistent with a fall in aggregate output below potential. Interestingly, however, the deviation in the responses of sectoral outputs between the optimal rule and aggregate output gap targeting narrow considerably after a couple of periods.

The extreme case of strict price inflation targeting is useful for illustrating the consequences of rules that place a high weight on stabilization of final goods price inflation. Because wages are sticky, the productivity shock to non-durables would cause unit labor cost to fall sharply in the absence of a large expansion of that sector's output gap; hence, given the large share of the nontraded sector, stabilization of aggregate inflation requires a large positive output gap in non-durables. While the expansion of the non-durables output gap under this policy is similar to that implied by standard one-sector models, the striking feature in our model is that the sizeable fall in real interest rates induces a massive boom in durables.

The hybrid wage-price inflation targeting rule implies responses that are similar to the case of aggregate output gap targeting (thus, for expositional simplicity, responses under the hybrid rule are not shown in figures 7-9[14]). The hybrid rule "corrects" for

[14] We include Figures 7a, 8a, and 9a following Figures 7-9 to show also the case of the hybrid wage-price rule (the graphs are otherwise identical).

the high degree of output gap volatility associated with price inflation targeting by also responding to the real wage markup. Intuitively, the hybrid rule distinguishes between the case in which low marginal costs and falling final goods prices are attributable to weak demand, and the case in which marginal costs are low due to incomplete wage adjustment following a favorable supply shock. In the former case, falling prices and wages encourage looser policy, expanding output towards potential. In the latter case – relevant in the case of this shock – rising wage pressure induces policy tightening, moving output closer to potential. Thus, the hybrid rule tends to come close to the policy of aggregate output gap targeting (although it does not *necessarily* force output gap variation to be close to zero on a period-by-period basis, since price and wage inflation rates respond to a discounted sum of future price and wage markups).

Figure 8 shows impulse responses to a productivity shock to durables under the alternative rules. Given sluggish relative price adjustment in durables, a hefty cut in real interest rates is required to avoid a large negative output gap in durables. In this case, interest rates are reduced more sharply under the optimal rule than under aggregate output gap targeting, again reflecting that it is desirable to avoid excessive volatility in sectoral output gaps. Accordingly, the aggregate output gap rises somewhat under the optimal rule. The responses under the wage-price hybrid rule are similar to the case of aggregate output gap targeting, although the hybrid rule generates a bit more volatility in the durables sector. Strict price inflation targeting requires the largest cut in real interest rates of the policies considered, and stimulates a substantial rise in output above potential in both sectors [15]

Figure 9 shows impulse responses to a shock to government spending. The optimal rule implies a significant decline in the real interest rate, in order to mitigate the contraction in the durable goods sector. Real interest rates also decline slightly initially under aggregate output gap targeting and under the hybrid wage-price targeting rule (again not shown, but very close to output gap targeting), though these policies induce a sharper contraction in durables than the optimal rule. Finally, inflation targeting is much "tighter" than the alternatives considered, implying a rise in real interest rates that leads to a sharp contraction in durables.

7.2 Welfare Implications

Tables 1 and 2A-2C allow an assessment of the welfare costs of alternative policies using the quadratic approximation to the social welfare function as the relevant measure of welfare. The welfare loss reported in columns 1-3 can be interpreted as the output loss per period under each policy expressed as a percentage of steady state output (multiplied by a constant scale factor of 10^{-2}).[16] Table 1 reports welfare losses

[15] Note that strict price inflation targeting tends to induce more persistent deviations of output from potential in each sector than the alternative policies; with forward-looking wage-setting, this also translates into a much higher degree of cross-sectional wage dispersion in each sector.

[16] It is important to note that the welfare losses reported in the tables are measured as a flow, and correspond to the expected loss each period under a given policy (thus, as seen in the sectoral loss functions in equations (35) and (38), the discounted expected loss functions are multiplied by (1-β)). Given our parameterization of $\beta = .993$, expected discounted losses are more than 100 times larger than what is reported in the tables.

under the full estimated variance-covariance matrix of the shocks. Welfare losses are also reported for a one standard deviation innovation to productivity in non-durables (Table 2A), durables (Table 2B), and to government spending (Table 2C).

One interesting feature suggested by the graphical analysis above is that the incorporation of durable goods significantly complicates the policymaker's stabilization problem: in particular, even under the optimal rule, shocks may induce sizeable fluctuations in output gaps, especially in the durables sector. Table 1 shows that that welfare losses attributable to the durable goods sector in fact exceed welfare losses in non-durables for all of the rules considered, including the optimal rule. The higher welfare losses in durables, notwithstanding the much smaller size of that sector, reflect both that the standard deviation of the (true) output gap in durables is several times larger than in non-durables, and also that the durables sector experiences more volatility in relative wages and prices.

Next, we compare the performance of the aggregate output gap targeting rule and the hybrid wage-price targeting rule to the optimal rule (the first three rows of each table). Our graphical analysis suggests that a shortcoming of aggregate rules is that they allow output variation in the durables sector to be somewhat larger than would occur under the optimal rule. This "excess variability in durables" problem is clearly reflected in the welfare losses. In particular, the primary reason that welfare is lower under these aggregate rules is that they induce greater welfare losses in the durables component (in part because they induce larger output gaps in durables, but also because they tend to induce higher relative wage and price variability).

However, aggregate output gap targeting and the hybrid wage-price rule still perform remarkably well, at least under the estimated historical distribution of shocks. Table 1 shows that the welfare losses under these rules are on average (i.e., under the estimated variance-covariance matrix of all the shocks) only around 10-20 percent higher than under the optimal rule. The slightly poorer overall performance of the hybrid wage-price rule reflects that it induces somewhat larger losses in response to the innovation to durables (Table 2B). In the case of the productivity shock to non-durables and the government spending shock, these two aggregate rules yield nearly identical outcomes.

The good welfare performance of these rules that keep aggregate output near potential reflects that the implied level of sectoral output dispersion is relatively low *given the magnitude and nature of the estimated shocks*. Thus, the benefits of a shifting to a rule that responds to sectoral gaps is fairly modest. For example, the unconditional standard deviation of the (true) output gap in durables turns out to be 2.66 percent under output gap targeting (not reported in the tables), while the unconditional standard deviation of the output gap in non-durables is 0.38 percent. The optimal rule would reduce the standard deviation of the output gap in durables to 1.73 percent, albeit at the cost of increasing the standard deviation of the output gap in non-durables to 0.60 percent.[17] Of course, with a considerably more volatile distribution of shocks, the difference between the level of volatility in the durable and non-durable sector would widen under aggregate output gap targeting, and there

[17]Note that these statistics measure the volatility of the "true" output gap, and are much smaller than the volatility of output in each sector. For example, output volatility in nondurables under output gap targeting is 1.51 percent, and in durables it is 8.43 percent.

would be somewhat greater benefit to following a rule that responded to sectoral variables.

As seen in row 4 of each table, the much higher level of sectoral output gap volatility under inflation targeting observed in the impulse responses translates into much higher welfare losses. Despite the small size of the durables sector, it makes a disproportionate contribution to the overall welfare loss. While welfare losses due to output gap variation are a major contributor to the overall welfare loss, inefficient fluctuations in relative wages are also important.

The tables also present welfare losses under the baseline monetary policy, and under the Taylor Rule (with a coefficient of 1.5 on the four-quarter change in price inflation, and 0.5 on the true output gap). The baseline rule exhibits some deterioration in performance relative to aggregate output gap targeting and the hybrid rule, though it generally performs reasonably well except in response to sector-specific shocks to durables. By contrast, Taylor's rule performs quite poorly compared with the rules that keep aggregate output near potential. Its key shortcoming is also apparent in models with only one productive sector; namely, it isn't reactive enough to keep aggregate output near potential. Given forward-looking price and wage-setting behavior, persistent deviations in output from potential induce a high degree of welfare-reducing variation in wages and prices. In our two-sector model, this problem is exacerbated, and Taylor's Rule generates relatively large losses in both sectors.

Overall, it seems quite remarkable that certain very simple aggregate rules can come close to the full commitment optimal rule, particularly given that the latter implies a complicated sector-specific reaction function. By inference, there would be even less to gain by shifting toward relatively simple sector-based rules, e.g., rules that responded differently to the output gap in each sector. Moreover, our results are particularly surprising given that certain features of our model framework, including the inability of resources to move across sectors, would appear *a priori* to bias our results in favor of a sector-based rule. Of course, it will be desirable in future research to examine the robustness of our results to various dynamic complications, including capital accumulation by firms, and to a somewhat broader class of shocks.

8 Conclusions

Our analysis indicates that it may *not* be necessary for a well-designed monetary policy rule to respond to sector-specific variables, even if social welfare depends explicitly upon them. In particular, while it seems clear that aggressive stabilization of final goods prices is undesirable, our results suggest that a somewhat broader concept of inflation-targeting in which the underlying basket is comprised of an index of both final goods prices and aggregate labor costs may perform well. With the appropriately chosen weights on aggregate price and wage inflation, such a policy comes close to stabilizing aggregate output at potential. Furthermore, given the estimated distribution of shocks, the level of sectoral output dispersion is reasonably close to that implied by the optimal full-commitment rule. Such a rule is clearly easier to implement and convey to market participants than the full-commitment rule. Moreover, while it achieves a similar outcome as a rule that directly targets the (true) aggregate output gap, it does not require direct knowledge of the level of potential output.

Finally, we caution that while our analysis suggests that certain aggregate rules may work well if the distribution of shocks resembles the historical average in U.S. data, it might be desirable to depart from such rules in the case of an increase in the variability of underlying shocks, or in the case of an unusually large shock. In the presence of shocks that generated a much higher degree of cross-sectional output dispersion, there would be larger potential gains in responding to sector-specific variables than indicated by our analysis.

Table 1. Welfare under Alternative Policies:

Estimated Variance-Covariance Matrix of Shocks[1]

	Welfare Loss			Loss cp
	Durables	Non-durables	Total	to Opt
Full Commitment	2.40	1.96	4.36	0
Output Gap Target	3.32	1.58	4.90	12.5
Wage-Price Target	4.16	1.14	5.30	21.6
Inflation Target	12.2	8.6	20.8	378
Estimated Rule	4.56	1.60	6.16	41.3
Taylor (true gap)	4.61	3.63	8.24	89.1

1/ The welfare loss is expressed as a percent of steady state output (multiplied by 10^{-2}).

Table 2A. Welfare under Alternative Policies: One Standard Deviation Innovation to Productivity in Non-durables[1]

	Welfare Loss			Loss cp
	Durables	Non-durables	Total	to Opt
Full Commitment	0.49	1.25	1.74	0
Output GapTarget	0.83	1.14	1.97	13.0
Wage-Price Target	1.07	0.93	2.00	15.1
Inflation Target	9.36	4.40	13.8	691
Estimated Rule	1.08	1.15	2.24	28.5
Taylor (true gap)	1.04	2.61	3.65	110

1/ The welfare loss is expressed as a percent of steady state output (multiplied by 10^{-2}).

Table 2B. Welfare under Alternative Policies: One Standard Deviation Innovation to Productivity in Durables[1]

	Welfare Loss			Loss cp
	Durables	Non-durables	Total	to Opt
Full Commitment	1.73	0.58	2.31	0
Output GapTarget	2.24	0.33	2.57	11.2
Wage-Price Target	2.77	0.15	2.92	26.8
Inflation Target	2.25	4.19	6.44	179
Estimated Rule	3.25	0.32	3.57	54.8
Taylor (true gap)	3.34	0.60	3.94	71.3

1/ The welfare loss is expressed as a percent of steady state output (multiplied by 10^{-2}).

Table 2C. Welfare under Alternative Policies: One Standard Deviation Innovation to Government Spending[1]

	Welfare Loss			Loss cp
	Durables	Non-durables	Total	to Opt
Full Commitment	0.18	0.13	0.31	0
Output GapTarget	0.26	0.11	0.37	18.5
Wage-Price Target	0.32	0.05	0.37	19.0
Inflation Target	0.59	0.02	0.60	94.9
Estimated Rule	0.23	0.12	0.35	12.6
Taylor (true gap)	0.23	0.41	0.64	109

1/ The welfare loss is expressed as a percent of steady state output (multiplied by 10^{-2}).

9 References

Anderson, G.S., Moore, G., 1985. A linear algebraic procedure for solving linear perfect foresight models. *Economic Letters* 17, 247-252.

Angeloni, Ignazio, Kashyap, Anil, Mojon, Benoit, and Daniele Terlizzese. 2002. The Output Consumption Puzzle: A Difference in the Monetary Transmission Mechanism in the Euro Area and United States. Manuscript.

Baxter, Marianne. 1996. Are Consumer Durables Important for Business Cycles? *Review of Economics and Statistics* 78, 147-155.

Blanchard, Olivier and Charles Kahn. 1980. The Solution of Linear Difference Models under Rational Expectations. *Econometrica* 48, 1305-1311.

Calvo, Guillermo. 1983. Staggered Prices in a Utility Maximizing Framework. *Journal of Monetary Economics* 12, 383-98.

Christiano, Lawrence and Martin Eichenbaum. 1992. Current Real-Business Cycle Theories and Aggregate Labor Market Fluctuations. *American Economic Review* 82, 430-450.

Christiano, Lawrence, Eichenbaum, Martin, and Charles Evans. 1999. Monetary Policy Shocks: What Have We Learned, and to What End? In: Taylor, John and Michael Woodford (Eds.), *Handbook of Macroeconomics.* Vol 1A, 65-148.

Christiano, Lawrence, Eichenbaum, Martin, and Charles Evans. 2001. Nominal

Rigidities and the Dynamic Effects of Shocks to Monetary Policy. National Bureau of Economic Research Working Paper no. 8403.

Clarida, Richard, Jordi Gali, and Mark Gertler. 2000. Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory. *Quarterly Journal of Economics* 115, 147-180.

Erceg, Christopher, Dale Henderson, and Andrew Levin. 2000. Optimal Monetary Policy with Staggered Wage and Price Contracts. *Journal of Monetary Economics* 46, 281-313.

Fuhrer, Jeffrey. 2000. Habit Formation in Consumption and Its Implications for Monetary-Policy Models. *American Economic Review* 90, 367-90.

Gali, Jordi. 1993. Variability of Durable and non-durable Consumption: Evidence for Six OECD Countries. *Review of Economics and Statistics* 75, 418-428.

Goodfriend, Marvin. 1997. Monetary Policy Comes of Age: A 20th Century Odyssey. *Federal Reserve Bank of Richmond Economic Quarterly* 83, 1–24.

Goodfriend, Marvin and Robert King. 1997. The New Neoclassical Synthesis and the Role of Monetary Policy. In: Bernanke, B.S., Rotemberg, J.J. (Eds.), *NBER Macroeconomics Annual 1997.* MIT Press: Cambridge, 231-283.

Hamburger, Michael J. 1967. Interest Rates and the Demand for Consumer Durable Goods. *American Economic Review* 57:5, pp. 1131-1153.

Henderson, Dale and Warwick McKibbin. 1993. A Comparison of Some Basic Monetary Policy Regimes for Open Economies: Implications of Different Degrees of

Instrument Adjustment and Wage Persistence. *Carnegie-Rochester Series on Public Policy* 39, 221-318.

Hornstein, Andreas and Jack Prashnik. 1997. Intermediate Inputs and Sectoral Comovement in the Business Cycle. *Journal of Monetary Economics* 40, 573-95.

King, R., Wolman, A., 1999. What Should the Monetary Authority Do When Prices are Sticky? In: Taylor, J. (Ed.), *Monetary Policy Rules.* University of Chicago Press: Chicago, 349-398.

Mankiw, Gregory, and Ricardo Reis. 2000. What Measure of Inflation Should a Central Bank Target? National Bureau of Economic Research Working Paper no. 9375.

Mishkin, Frederic S. 1976. Illiquidity, Consumer Durable Expenditure, and Monetary Policy. *American Economic Review* 66, 642-654.

Ogaki, Masao and Carmen M. Reinhart. 1998. Measuring Intertemporal Substitution: The Role of Durable Goods. *Journal of Political Economy* 106, 1078-1098.

Orphanides, Athanasios, and Volker Wieland. 1998. Price Stability and Monetary Policy Effectiveness when Nominal Interest Rates are Bounded at Zero. Finance and Economics Discussion Paper no. 98-35. Washington, D.C.: Board of Governors of the Federal Reserve System.

Parks, Richard W. 1974. The Demand and Supply of Durable Goods and Durability. *American Economic Review* 64, pp. 37-55.

Rotemberg, Julio and Michael Woodford. An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy. In: Bernanke, Ben and Julio Rotemberg (Eds.), *NBER Macroeconomics Annual 1997*. MIT Press: Cambridge, 297-346.

Sims, Christopher. 1980. Macroeconomics and Reality. *Econometrica* 48, 1-48.

Taylor, John. 1980. Aggregate Dynamics and Staggered Contracts. *Journal of Political Economy* 88, 1-24.

Taylor, John B. 1993. Discretion versus Policy Rules in Practice. *Carnegie-Rochester Series on Public Policy* 39, 195-214.

Whelan, Karl. 2000. A Guide to the Use of Chain-Aggregated NIPA Data. Finance and Economics Discussion Paper no. 2000-35. Washington, D.C.: Board of Governors of the Federal Reserve System.

Figure 1

Empirical Responses to Monetary Policy Shock: Components of Investment

(sample 1966:1-2000:4, with two standard deviation confidence bands)

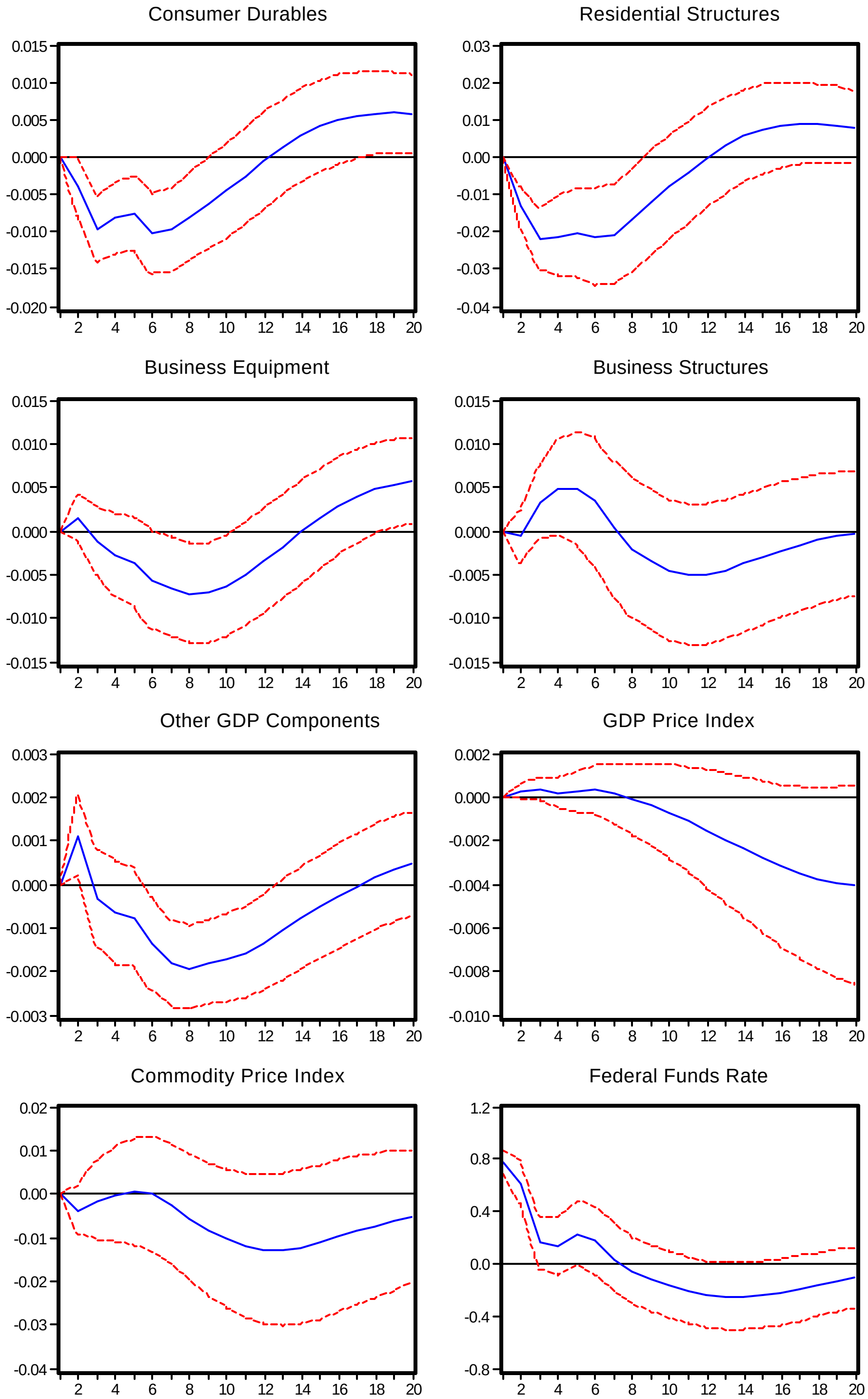

Figure 2A

Empirical Responses to Monetary Policy Shock: Durables vs. Other GDP

(sample 1966:1-2000:4, with two standard deviation confidence bands)

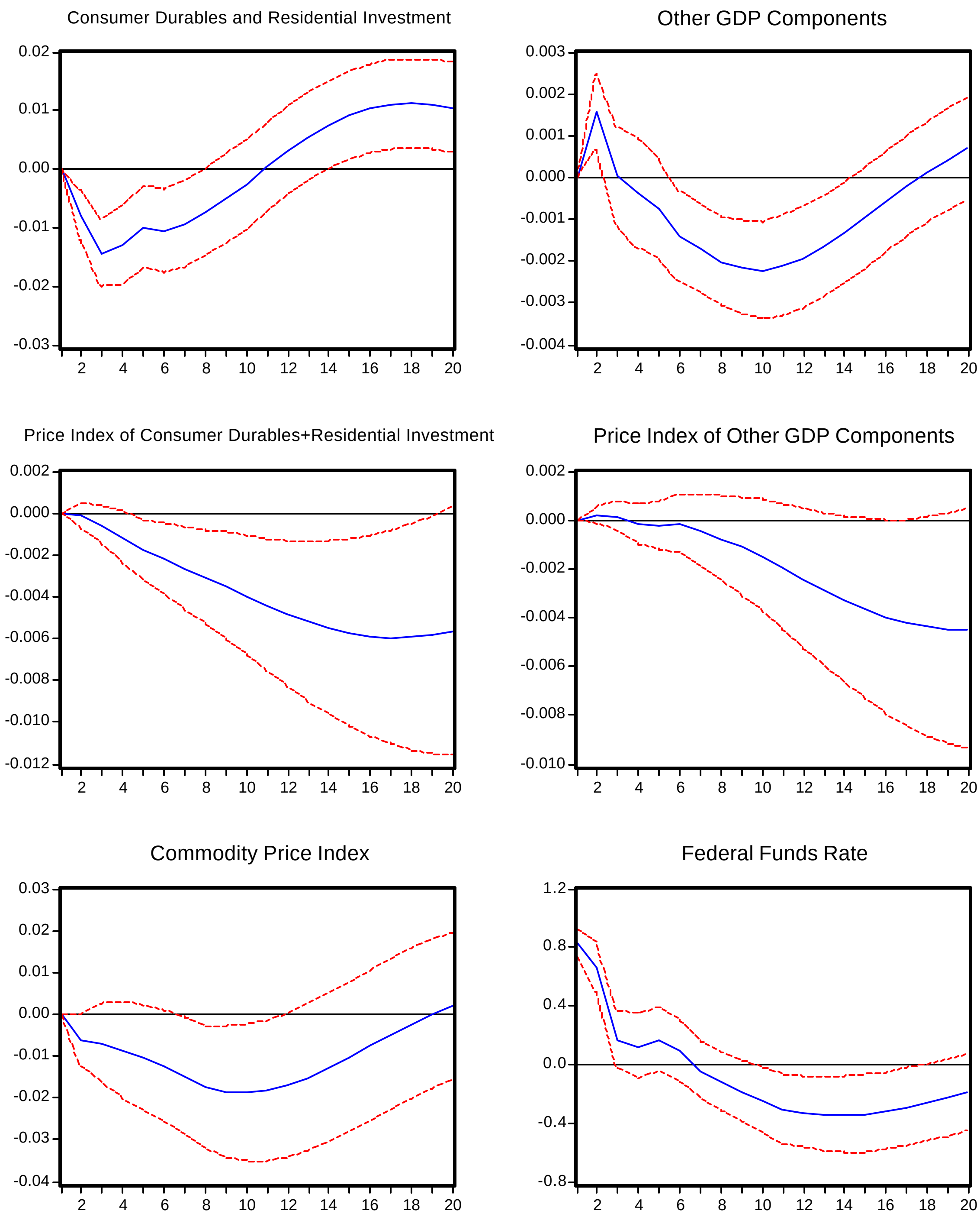

Figure 2B

Empirical Responses to Monetary Policy Shock: Durables vs. Other GDP

(short sample 1980:1-2000:4, with two standard deviation confidence bands)

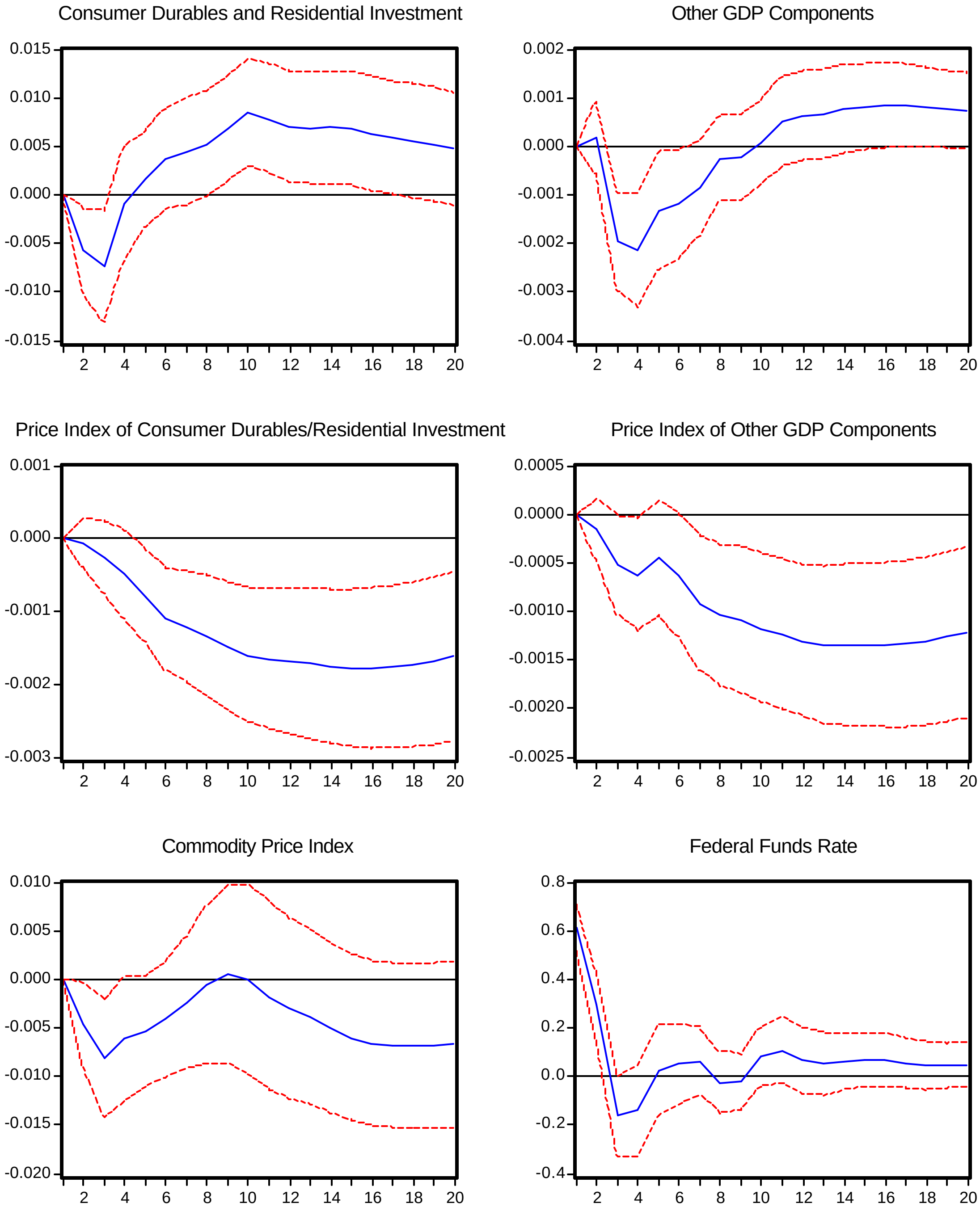

Figure 3. Baseline Model Dynamics: Monetary Policy Shock

(One standard deviation innovation)

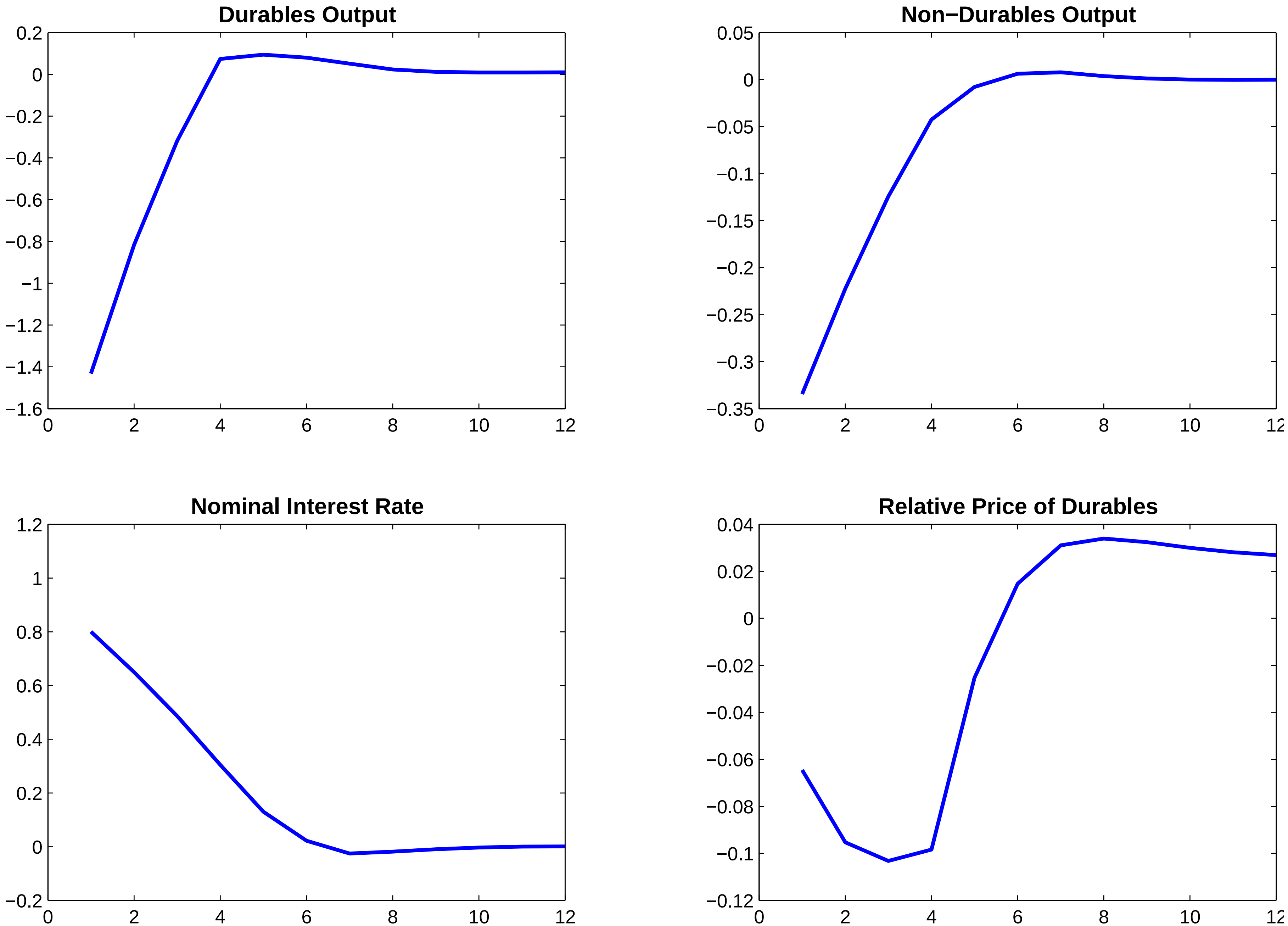

Figure 4. Baseline Model Dynamics: Productivity Shock to Non-durables

(One standard deviation innovation)

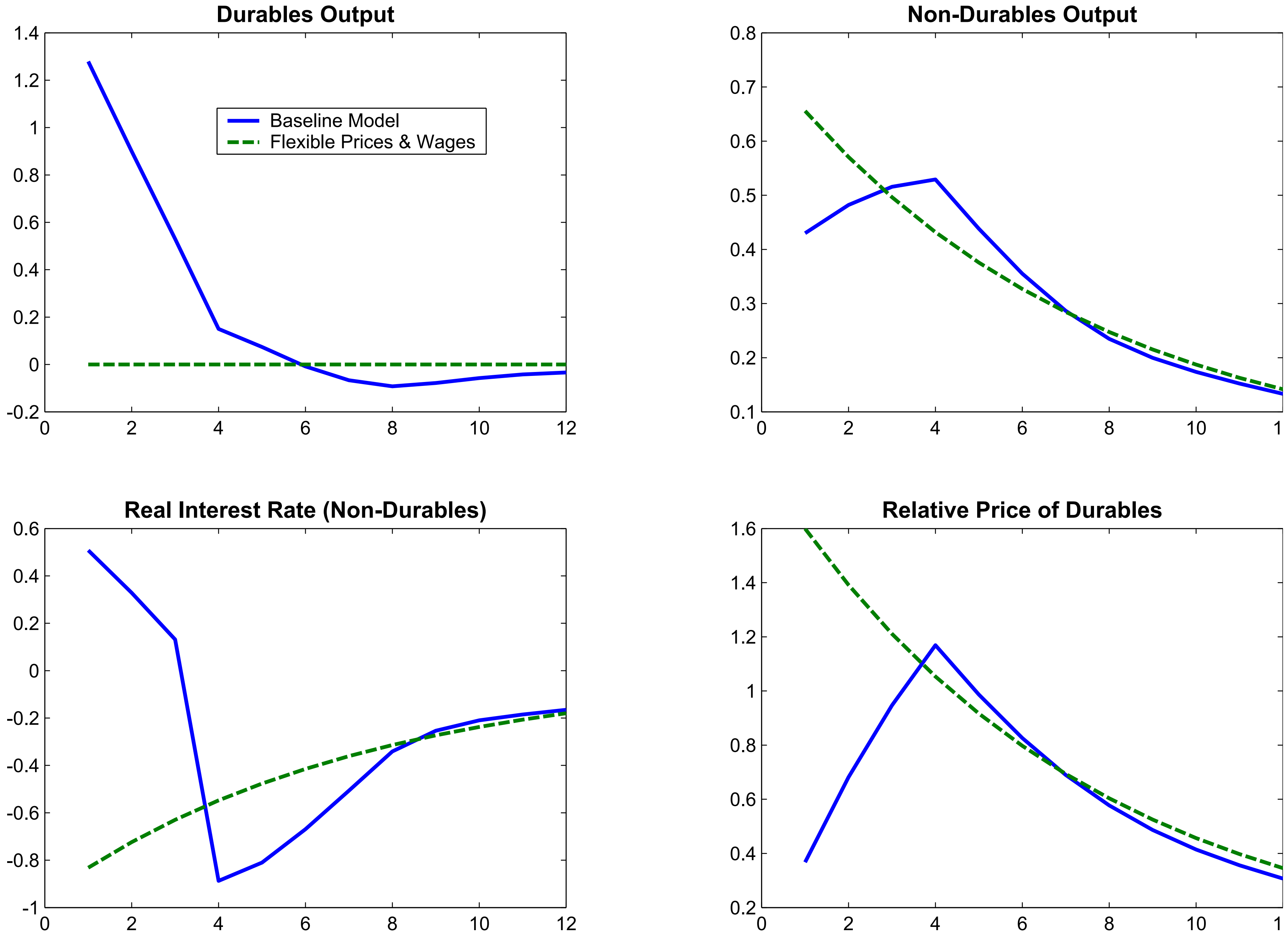

Figure 5. Baseline Model Dynamics: Productivity Shock to Durables

(One standard deviation innovation)

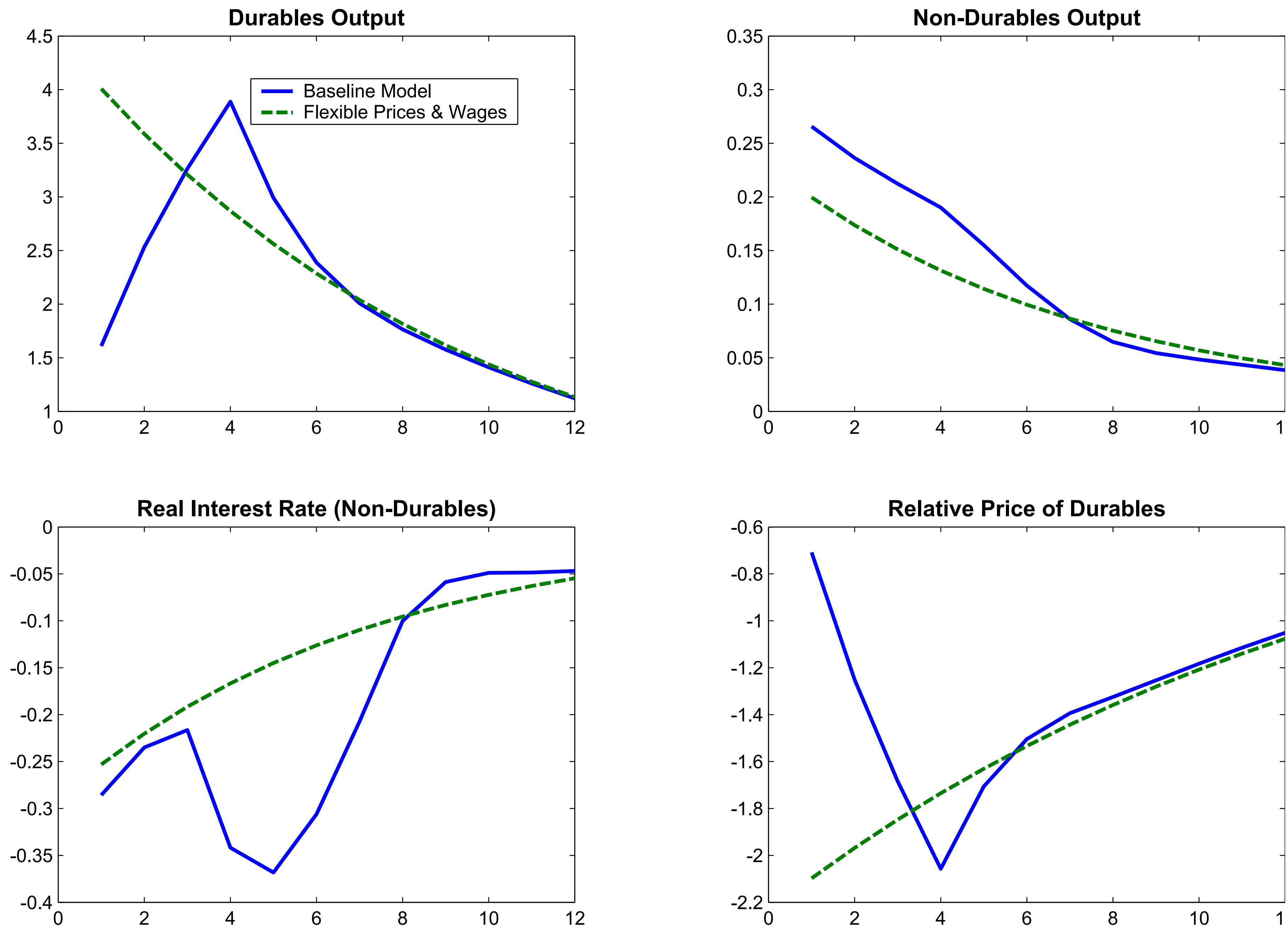

Figure 6. Baseline Model Dynamics: Government Spending Shock

(One standard deviation innovation)

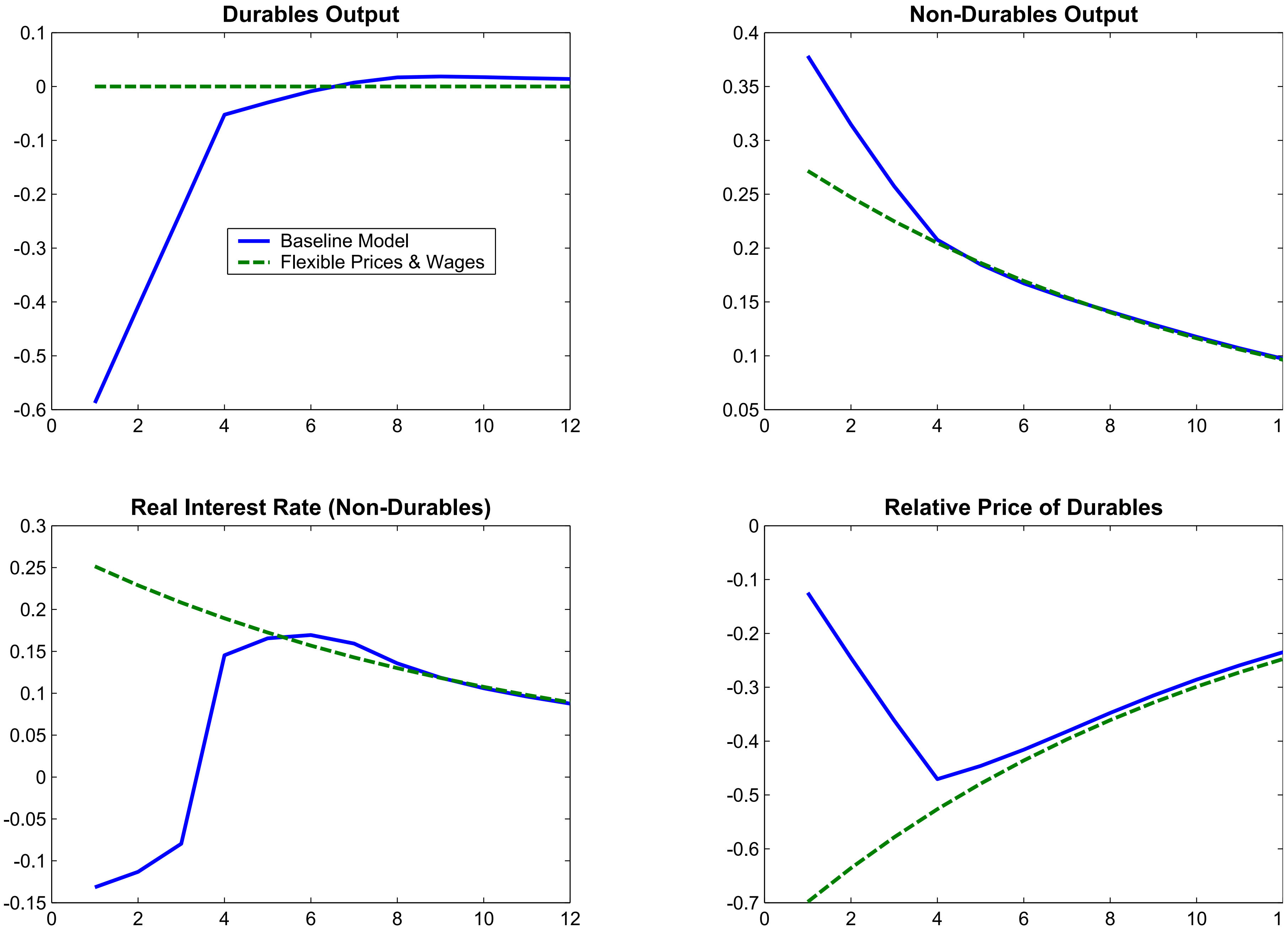

Figure 7. Policy Rule Comparison: Productivity Shock to Non-durables

(One standard deviation innovation)

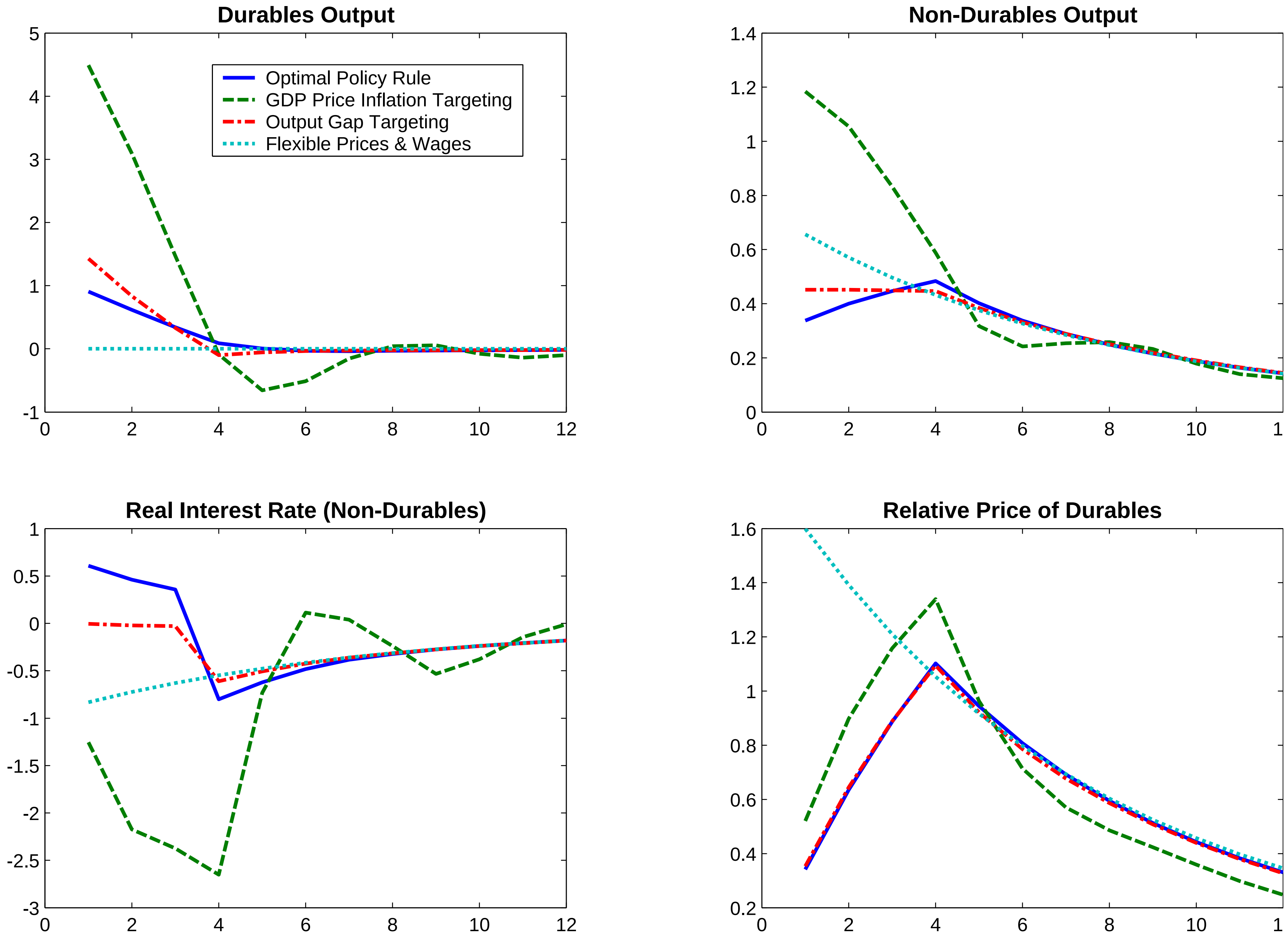

Figure 8. Policy Rule Comparison: Productivity Shock to Durables

(One standard deviation innovation)

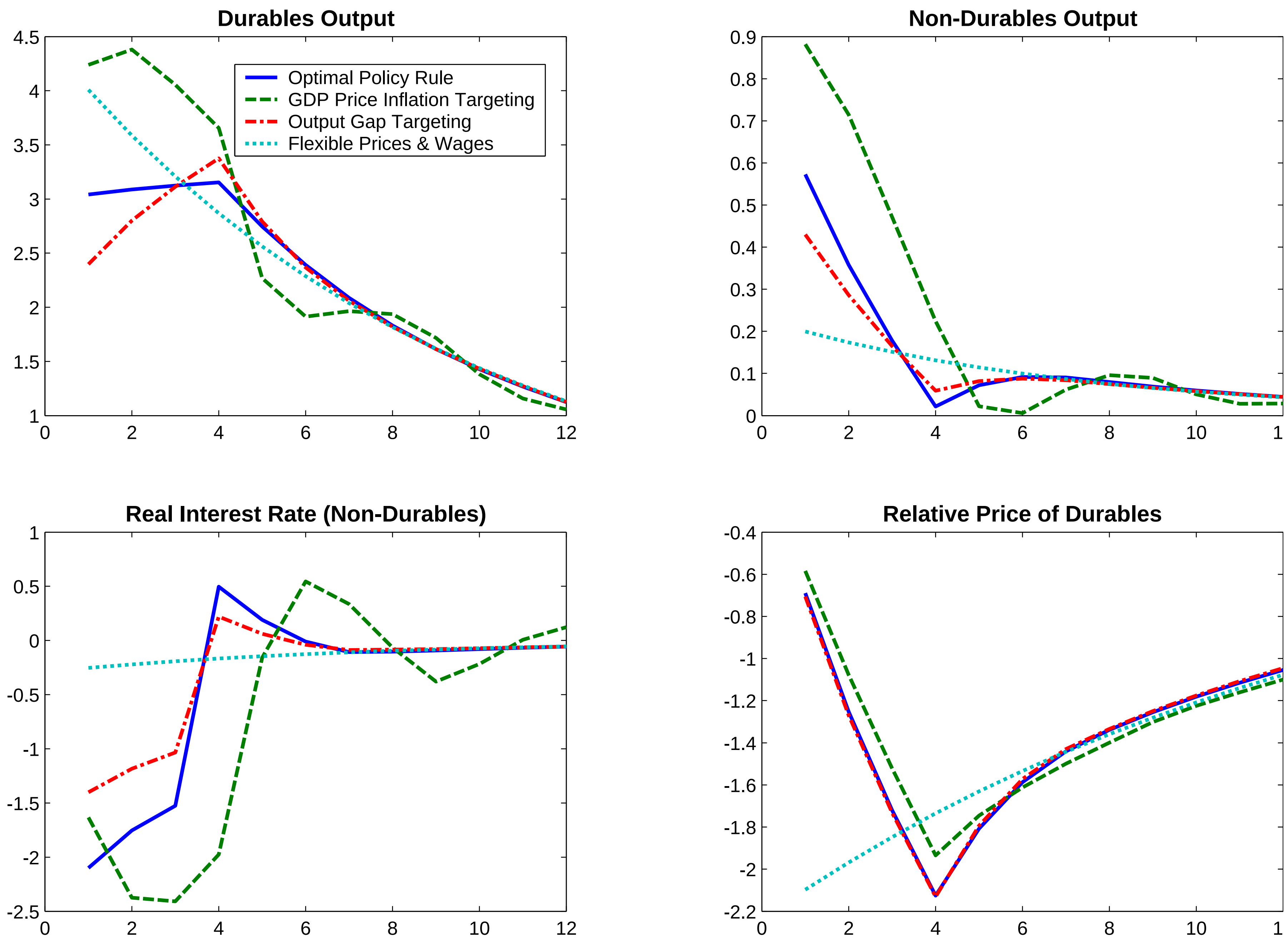

Figure 9. Policy Rule Comparison: Government Spending Shock

(One standard deviation innovation)

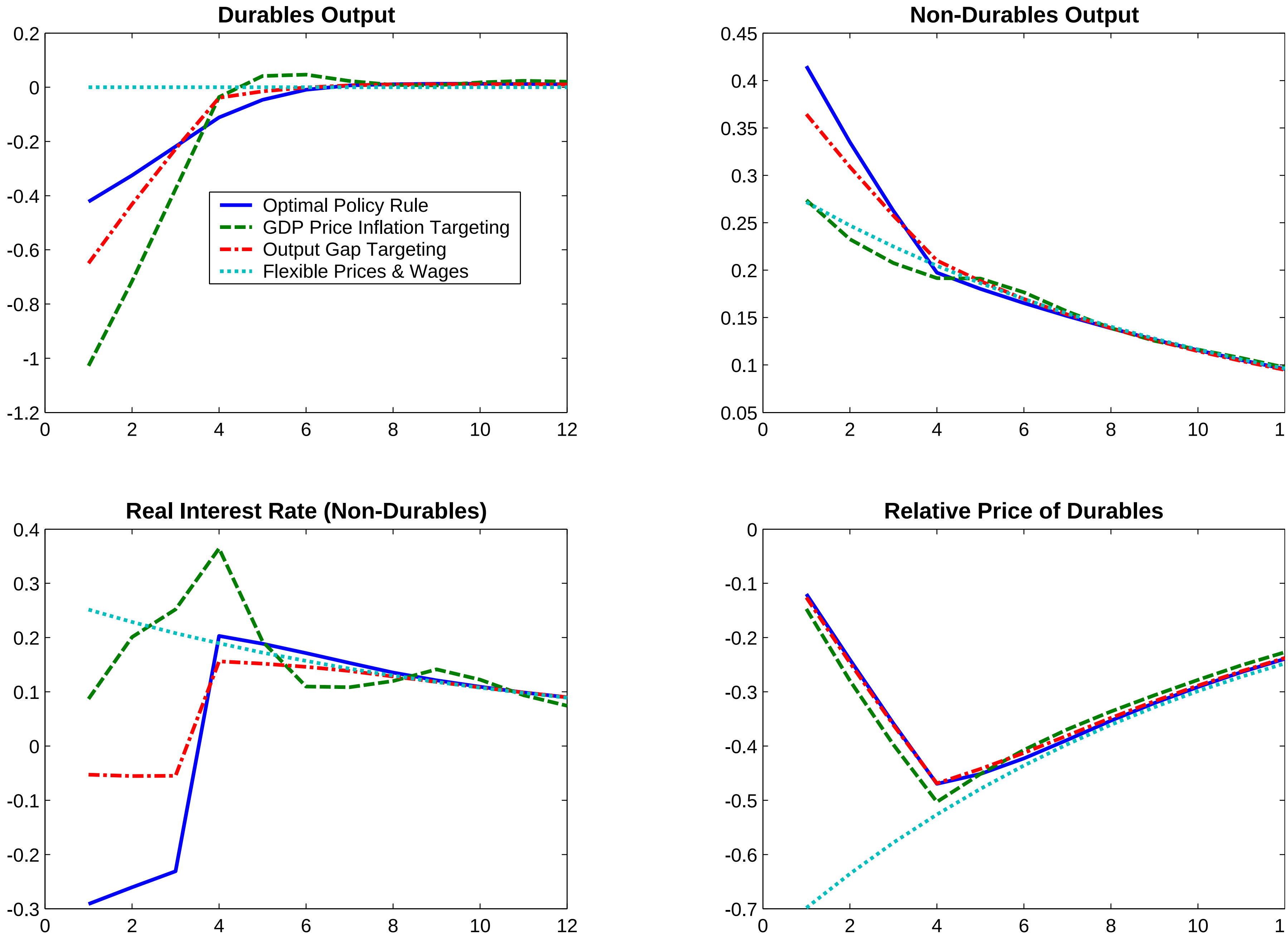

Figure 7A. Policy Rule Comparison: Productivity Shock to Non-durables

(One standard deviation innovation)

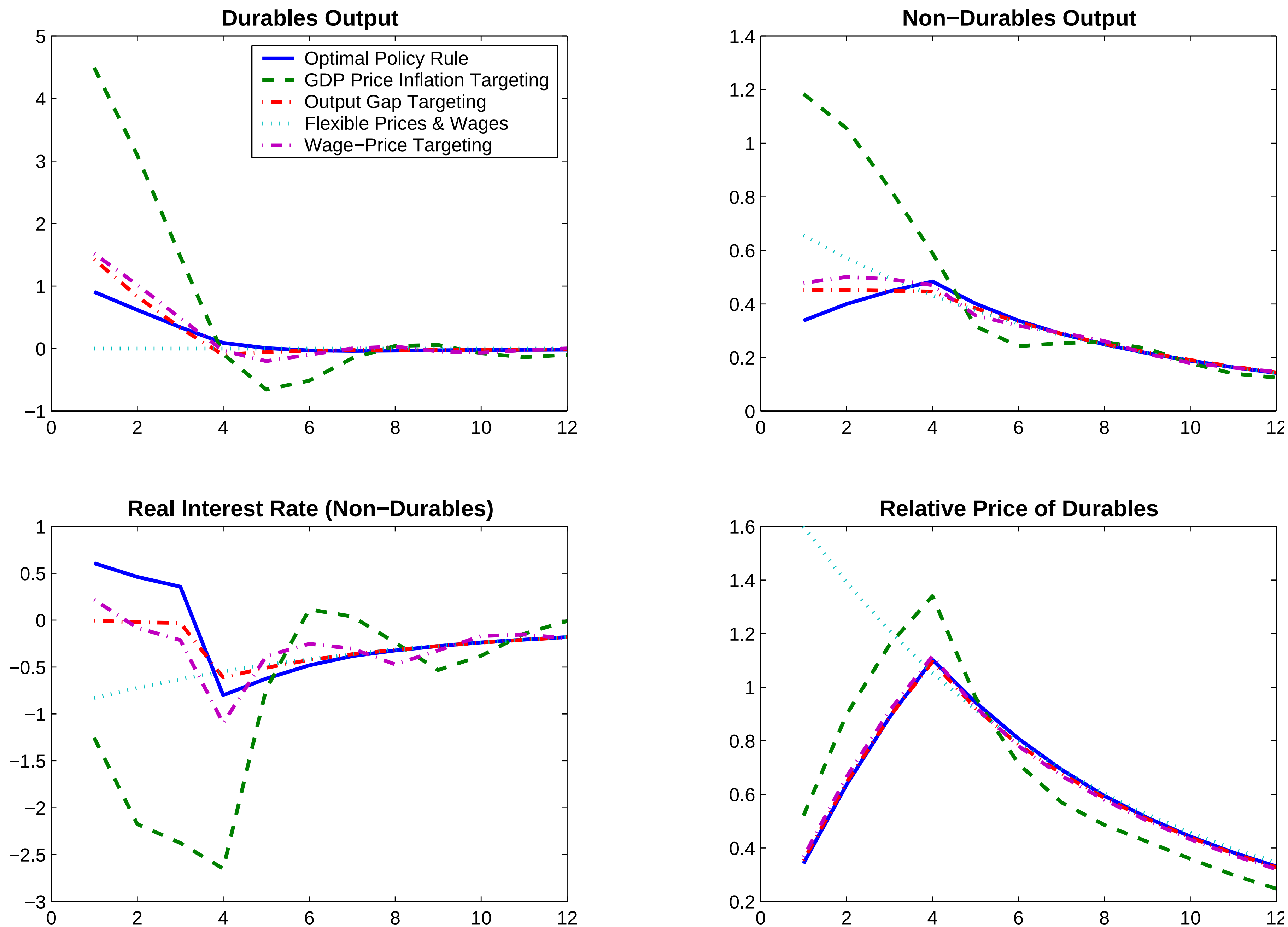

Figure 8A. Policy Rule Comparison: Productivity Shock to Durables

(One standard deviation innovation)

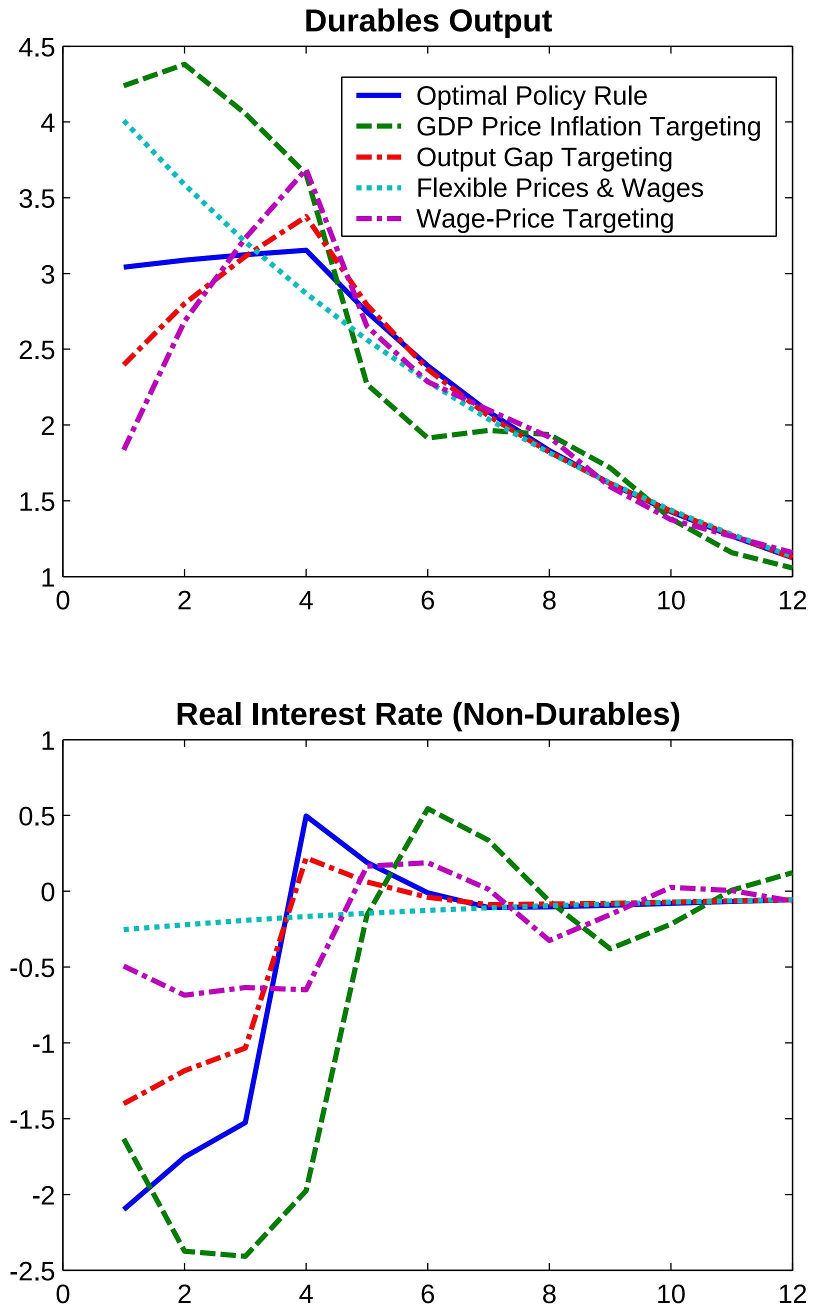

Figure 9A. Policy Rule Comparison: Government Spending Shock

(One standard deviation innovation)