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Nominal Rigidities, Monetary Policy and Pigou Cycles

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Nominal Rigidities, Monetary Policy and Pigou Cycles*

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Abstract

Based on a two sector dynamic new Keynesian model with sticky prices, this paper makes two contributions to the Pigou cycle literature. First, the paper quantifies the contribution of 'news shocks' – signals of future productivity changes. Maximum likelihood estimates indicate that nondurable sector news shocks are roughly as volatile as contemporary shocks; in the durable good sector, the standard deviation of news shocks is $\frac{1}{4}$ that of contemporaneous shocks. Second, and perhaps more importantly, the paper shows that the estimated interest rule contributes to Pigou cycles arising from nondurable sector news shocks. In particular, the Ramsey-optimal policy does not exhibit Pigou cycles while the estimated policy rule does. With sticky prices, intermediate good producers set current prices based on expected future marginal cost. The news shock implies a lower future marginal cost, and so nondurable goods prices start falling immediately. The estimated interest rate rule then prescribes a lower nominal interest rate, and so a fall in both the real interest rate and user cost of durables. As a result, purchases of durables also rise. In contrast, the Ramsey-optimal policy requires a *higher* nominal interest rate because the Ramsey policy attempts to minimize the distortions associated with within-sector price dispersion. The resulting dynamics under the Ramsey policy are, then, essentially the opposite of those under the estimated policy. Put simply, Pigou cycles arise in the model precisely because the central bank accommodates them.

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1 Introduction

Recent interest in Pigou cycles was piqued by Beaudry and Portier (2004). In essence, Pigou cycles refer to economic fluctuations driven, at least in part, by *news shocks* meaning signals of future productivity. More specifically, a positive news shock should result in a boom in economic activity prior to the realization of the shock. Beaudry and Portier (2004) studied circumstances in which the news shock was followed by an exactly offsetting contemporaneous shock to productivity that leads to a contraction in economic activity.

This paper explores the role of monetary policy in generating Pigou cycles. Money is held by households in order to satisfy a cash-in-advance constraint. As in much of the Pigou cycle literature, on the production side, there are two sectors, durables and nondurables. Each sector is populated by monopolistically competitive intermediate goods producers whose goods serve as inputs to a sector-specific final good. Following the dynamic new Keynesian (DNK) literature, intermediate goods firms periodically reoptimize their prices as in Calvo (1983). Details of the model are presented in Section 2.

Parameters for the benchmark model are obtained by a combination of calibration and maximum likelihood estimation. As discussed in Section 3.1, certain parameters are difficult to estimate and so are calibrated instead. In terms of the model's results, the important parameters are estimated, including: the elasticity of substitution between durable and nondurable goods in households' preferences; the parameters of the interest rate rule that characterizes monetary policy; the degree of nominal rigidity in each sector; and the parameters governing the shock processes, including the news and contemporaneous shocks to the durable and nondurable goods sectors, and the lag between observing a news shock and its effects on productivity being realized. An important contribution of the paper, then, is providing estimates of the size of news shocks. As reported in Section 3.1, nondurable sector news shocks are slightly larger than contemporary shocks while durable sector news shocks are about 25% the size of contemporary shocks in that sector. Further evidence concerning the importance of news shocks is presented in Section 3.3 which performs a forecast error variance decomposition of the model's shocks. At medium to long horizons, news shocks account for about half of aggregate output and inflation volatility.

The key finding is that following a nondurable sector news shock, output in both the durable and nondurable goods sectors increase, as do aggregate output and labor. In other words, the model economy exhibits Pigou cycles in response to nondurable sector news shock (but not durable sector news shocks). These results are summarized in Section 3.2. Here is the intuition for this result. The presence of nominal price rigidities make intermediate goods firms forward-looking in their price setting behavior. Knowing that their marginal cost will be lower in the future, nondurable sector intermediate goods producers start lowering their prices immediately. Households start buying more nondurable goods, and owing to the complementarity between durables and nondurables, also increase their purchases of durable goods as well. Thus, a boom is observed in both sectors prior to the actual realization of the nondurable sector news shock.

While the previous paragraph gives a large part of the story, it is not the whole story. In particular, the estimated interest rate rule characterizing monetary policy plays a role in generating Pigou cycles. This point is made by comparing the behavior of the model following a nondurable sector news shock across two distinct monetary policies: the estimated interest rate rule, and the policy that results from solving a Ramsey problem, presented in Section 2.5.2. In particular, the Ramsey-optimal policy does *not* result in Pigou cycles. Under the Ramsey policy, the central bank attempts to minimize the welfare consequences of two distortions. The first is the resource misallocation associated with within-sector price dispersion arising from staggered price reoptimization. The second is the distortion owing to the cash-in-advance constraint. The first distortion is minimized by setting inflation to zero while the second is minimized by deflating at the real interest rate. Since the Ramsey policy delivers an average inflation rate close to zero, the within-sector price distortion is evidently the more important one. Following a nondurable sector news shock, the Ramsey-optimal monetary policy sees the nominal interest rate *rise* whereas the estimated interest rate rule prescribes a *fall*. The effect of the rise in the nominal interest rate under the Ramsey policy is to raise both the real interest rate and the user cost of durables (defined in Section 2.1) which serves to dissuade households from accumulating durables and, owing to the complementarity between durables and nondurables, dampening their purchases of nondurables. The effect of this policy is to smooth out the inflationary consequences of this shock on nondurable sector inflation, albeit at the cost of pushing up durable sector inflation. In other words, Pigou cycles arise in the estimated model because monetary policy accommodates such cycles.

The framework in this paper is closely related to the recent development of two sector models with nominal rigidities (but no news shocks). Aoki (2001) studies optimal monetary policy responses to relative-price changes in a two-sector framework with a flexible-price sector and a sticky-price sector. Benigno (2004) evaluates monetary policy in a currency area where price rigidities may differ between countries. Barsky et al. (2007) explore the comovements of nondurable and durable goods sectors in response to a monetary shock in a two sector model with nominal rigidities and long-lived durable goods.[1] Erceg and Levin (2006) study optimal monetary policy in a two sector model with durable goods. They highlight the distinction between the nondurable and durable sectors in that the durable goods sector is much more interest-sensitive than the nondurable sector. Monacelli (2008, 2009) introduces collateral constraints into a two-sector model with nondurable and durable goods to study the co–movements in these two sectors in response to monetary policy shocks and optimal monetary issues.

Other related papers include Christiano et al. (2008) and Jaimovich and Rebelo's (2009) research on the possibility of generating expectation driven business cycles in one sector models. They succeed in generating booms and busts in consumption, investment and output by adding investment adjustment costs, variable utilization of capital and habit persistence into a standard one sector model. However, it is not that straightforward to get corresponding booms and busts of asset prices in their frameworks. Asset prices unexpectedly slump during the booms when all the other variables rise as expected. To solve this problem, Christiano et al. (2008) extend their model by adding sticky prices, sticky wages and standard Taylor-rule monetary policies. Compared with their frameworks, the model below involves fewer real and nominal rigidities.

The model is presented in Section 2; its estimation and simulation in Section 3.1. Section 4 investigates the sources of Pigou cycles in the modeling environment. Section 5 contains some concluding remarks.

2 Economic Environment

There are two sectors, durables and nondurables. Each sector has a continuum of sector-specific intermediate good producers, and a continuum of final good producers. Each intermediate good producer

[1] In Barsky et al. (2007), money demand is proportional to nominal purchases. This specification of money demand abstracts from the transactional distortions of money, focusing instead on the deleterious effects of relative price distortions. Section 4.3 shows that the results in this paper are qualitatively unchanged by using their specification of money demand.

uses labor to produce a differentiated good, and so acts as a monopolistic competitor. Prices are set in a staggered fashion à la Calvo (1983). Final good producers bundle together sector-specific intermediate goods to produce a sector-specific final good, acting as perfect competitors. Household supply labor and buy final goods, deriving utility from consumption of nondurables and the stock of durables. A central bank conducts monetary policy.

2.1 Households

The representative household has preferences over state contingent streams of nondurables, C_t, durables, D_t, and labor, N_t, summarized by

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, D_t, N_t), \quad 0 < \beta < 1. \tag{1}$$

The functional form of U is

$$U(C,D,N) = \ln\left[(1-\alpha)^{\frac{1}{\eta}} C^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} D^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} - \upsilon \frac{N^{1+\sigma}}{1+\sigma} \tag{2}$$

where $\eta > 0$ is the elasticity of substitution between durables and nondurables, and α governs the importance of durables relative to nondurables.

The household's purchases of nondurables and durables is subject to the cash-in-advance constraint,

$$P_{ct} C_t + P_{dt} \left[D_t - (1-\delta) D_{t-1}\right] \leq M_{t-1} \tag{3}$$

where P_{ct} is the price of nondurables, P_{dt} the price of durables and M_{t-1} is nominal money balances brought into the period. The term in square brackets is newly purchased durables; δ is their depreciation rate.

The household hires out its time, N_t, at nominal wage W_t. In addition to money balances, the household also brings into the period bonds, B_{t-1}, that pay a gross rate of return, R_{t-1}. The household also receives a transfer from government, T_t, and its share of profits from intermediate nondurable goods producers, Π_{ct}, and from intermediate durable goods producers, Π_{dt}. The household's budget constraint is, then,

$$P_{ct}C_t + P_{dt}\left[D_t - (1-\delta)D_{t-1}\right] + B_t + M_t = W_tN_t + R_{t-1}B_{t-1} + M_{t-1} + T_t + \Pi_{ct} + \Pi_{dt}. \tag{4}$$

The household chooses contingent sequences, $\{C_t, D_t, N_t, B_t, M_t\}_{t=0}^{\infty}$, to maximize Eq. (1) subject to Eqs. (3) and (4) given B_{-1} and M_{-1}. The Euler equations are

$$q_tU_c(C_t,D_t,N_t) = U_d(C_t,D_t,N_t) + \beta E_t\left\{q_{t+1}U_c(C_{t+1},D_{t+1},N_{t+1})(1-\delta)\right\} \tag{5}$$

$$\frac{U_n(C_t,D_t,N_t)}{W_t} = \beta E_t\left\{R_t\frac{U_n(C_{t+1},D_{t+1},N_{t+1})}{W_{t+1}}\right\} \tag{6}$$

$$-\frac{U_n(C_t,D_t,N_t)}{W_t} = \beta E_t\left\{\frac{U_c(C_{t+1},D_{t+1},N_{t+1})}{P_{c,t+1}}\right\} \tag{7}$$

where $q_t \equiv P_{dt}/P_{ct}$ is the price of durables relative to nondurables. Eq. (5) is the durables accumulation equation, trading off the benefits of an additional unit of durables against its cost in foregone nondurable consumption. Eq. (6) governs the accumulation of bonds. Finally, Eq. (7) is a fairly standard condition that arises in cash-in-advance models, reflecting the fact that labor earnings in the current period cannot be spent until the next.

As pointed out by Barsky et al. (2007), when durables are long lived, the shadow price of durables is roughly constant following a temporary shock. To see this point, let γ_t be the shadow price of a unit of durables and iterate forward on Eq. (5):

$$\begin{aligned}\gamma_t &= q_tU_c(C_t,D_t,N_t)\\ &= U_d(C_t,D_t,N_t) + \beta(1-\delta)E_t\left\{U_d(C_{t+1},D_{t+1},N_{t+1})\right\}\\ &\quad + \beta^2(1-\delta)^2E_t\left\{U_d(C_{t+2},D_{t+2},N_{t+2})\right\} + \cdots.\end{aligned} \tag{8}$$

If durables are long lived, then their depreciation rate, δ, is close to zero and the stock of durables is large relative to investment in durables. In this case, the stock of durables does not change much in response to shocks to the economy, either news shocks or conventional (contemporaneous) productivity shocks. Consequently, the right-hand side of Eq. (8) is roughly constant in the face of such shocks. Fluctuations in the relative price of durables will manifest themselves in changes in nondurable consumption in order to bring the marginal utility of nondurables in line with the near constant right-hand side of Eq. (8).

Eq. (5) can, alternatively, be written as

$$U_d(C_t,D_t,N_t) = U_c(C_t,D_t,N_t)\underbrace{\left[q_t - \beta(1-\delta)E_t\left\{q_{t+1}\frac{U_c(C_{t+1},D_{t+1},N_{t+1})}{U_c(C_t,D_t,N_t)}\right\}\right]}_{\text{user cost}}. \tag{9}$$

Eq. (9) says that if the household gives up one unit of durables at t, at utility cost $U_d(C_t,D_t,N_t)$, it can purchase q_t units of nondurables. These additional units of nondurables increase utility by $q_tU_c(C_t,D_t,N_t)$. However, the household will have fewer durables in the future which lowers its utility; this effect is captured by the remaining terms in Eq. (9). Put differently, the user cost of durables is its (relative) purchase price less the present value of its resale value.

2.2 Final Good Producers

The durable and nondurable goods sectors are, in terms of notation, the same. So, consider sector j (either durables, d, or nondurables, c). Perfectly competitive final goods producers purchase intermediate goods, $Y_{jt}(i)$, to "assemble" final goods using the technology

$$Y_{jt} = \left[\int_0^1 Y_{jt}(i)^{\frac{\varepsilon_j-1}{\varepsilon_j}}di\right]^{\frac{\varepsilon_j}{\varepsilon_j-1}}, \tag{10}$$

where $\varepsilon_j > 0$ is the elasticity of substitution between the differentiated goods in sector j. This setup is quite common in the DNK literature. The final goods firm's cost minimization problem leads to the demand function for intermediate good i,

$$Y_{jt}(i) = \left(\frac{P_{jt}(i)}{P_{jt}}\right)^{-\varepsilon_j} Y_{jt} \tag{11}$$

where $P_{jt} = \left(\int_0^1 P_{jt}(i)^{1-\varepsilon_j}di\right)^{\frac{1}{1-\varepsilon_j}}$ is the price of final good j.

2.3 Intermediate Goods Firms

Each sector is populated by a continuum of intermediate firms indexed by $i \in [0,1]$. Firm i faces the demand function Eq. (11) and has access to a technology that only uses labor:

$$Y_{jt}(i) = A_{jt}N_{jt}(i) \tag{12}$$

where A_{jt} is the sector-wide state of technology in sector j.

As in much of the DNK literature, firms probabilistically are able to reoptimize their prices as in Calvo (1983). Specifically, with probability $(1-\omega_j)$, a firm in sector j is able to reoptimize its price; with probability ω_j it cannot. The reoptimization probability is independently and identically distributed across firms and over time. Firms that do not reoptimize their price increase their price by the steady state inflation rate. When a firm can reoptimize its price, it sets its price P^*_{jt} to maximize the following expression for expected discounted profits:

$$E_t \sum_{k=0}^{\infty} \omega_j^k \Delta_{t,t+k} \left[\frac{(1+\tau_j)\pi^k P^*_{jt}}{P_{c,t+k}} Y_{j,t+k} - MC_{j,t+k} Y_{j,t+k} \right] \tag{13}$$

where $MC_{jt} = W_t/(A_{jt}P_{ct})$ is the firm's real marginal cost, π is the steady state gross inflation rate, and $\Delta_{t,t+k}$ is the firm's stochastic discount factor. Since firms are assumed to act in the best interests of their owners (that is, households), $\Delta_{t,t+k} = \beta^k U_c(C_{t+k}, D_{t+k}, N_{t+k})/U_c(C_t, D_t, N_t)$, meaning that the firm discounts real profits (measured in units of the nondurable good), the term in square brackets in Eq. (13), according to the marginal rate of substitution for nondurable goods over time.

In Eq. (13), τ_j is a fixed subsidy rate. As in Rotemberg and Woodford (1997), setting $\tau_j = \frac{1}{\varepsilon_j - 1}$ offsets the distortions to steady state output induced by the markup associated with monopolistic pricing.

In setting its price at t, the firm takes into account the fact that it may have to wait some time until it is able to reoptimize its price. In particular, the probability of not reoptimizing between dates t and $t+k$ is ω_j^k. Since all reoptimizing firms face the same problem, all will choose the same P^*_{jt}. The first-order condition of Eq. (13) yields

$$P_{jt}^{*} = \frac{1}{1+\tau_j}\frac{\varepsilon_j}{\varepsilon_j - 1}\frac{E_t \sum_{k=0}^{\infty} \omega_j^k \beta^k \pi^{-\varepsilon_j k} U_c(C_{t+k}, D_{t+k}, N_{t+k}) MC_{j,t+k} Y_{j,t+k} P_{j,t+k}^{\varepsilon_j - 1} P_{c,t+k}}{E_t \sum_{k=0}^{\infty} \omega_j^k \beta^k \pi^{(1-\varepsilon_j)k} U_c(C_{t+k}, D_{t+k}, N_{t+k}) Y_{j,t+k} P_{j,t+k}^{\varepsilon_j - 1}}. \tag{14}$$

Given that the opportunity to reoptimize prices arrives probabilistically to each firm each period, the sectoral price index satisfies the recursion,

$$P_{jt} = \left[(1-\omega_j)(P_{jt}^{*})^{1-\varepsilon_j} + \omega_j(\pi P_{j,t-1})^{1-\varepsilon_j}\right]^{\frac{1}{1-\varepsilon_j}}. \tag{15}$$

For future reference, the sectoral gross inflation rate is $\pi_{jt} \equiv P_{jt}/P_{j,t-1}$.

Given how nondurable and durable goods aggregate in preferences (see Eq. (2)), the price index for aggregate final goods is given by

$$P_t = (P_{ct}Y_{ct} + P_{dt}Y_{dt})/(Y_{ct} + Y_{dt}) \tag{16}$$

and the aggregate gross inflation rate is $\pi_t \equiv P_t/P_{t-1}$.

2.4 Productivity

As in Beaudry and Portier (2004) and Christiano et al. (2008), productivity in sector j follows an autoregressive process:

$$\ln A_{jt} = \rho_j \ln A_{j,t-1} + \xi_{j,t-p} + \zeta_{jt}, \quad |\rho_j| < 1 \tag{17}$$

where $\xi_{j,t-p} \sim N(0, \sigma_{\xi j}^2)$ is the *news shock* while $\zeta \sim N(0, \sigma_{\zeta j}^2)$ is a conventional, *contemporary productivity shock*. With regards to the news shock, notice that at time $t-p$, agents receive 'news' that sector j productivity will change at date t. For concreteness, consider a positive news shock: $\xi_{j,t-p} > 0$ meaning that from time $t-p$ to $t-1$, agents expect an improvement in sector j productivity at t. At time t, the contemporaneous shock, ζ_{jt} is realized. This contemporaneous shock could reinforce the news shock ($\zeta_{jt} > 0$), partially offset it ($-\xi_{j,t-p} < \zeta_{jt} < 0$), exactly offset the news shock ($\zeta_{jt} = -\xi_{j,t-p}$), or swamp it out ($\zeta_{jt} < -\xi_{j,t-p}$). Early work in the Pigou cycle literature focused on the special case in which the contemporary shock exactly offset the news shock; see Beaudry and Portier (2004).

2.5 Monetary Policy

Two alternative characterizations of monetary policy are considered: (1) the central bank follows an interest rate rule; and (2) the central bank follows the policy prescribed by solving a Ramsey problem.

2.5.1 Interest Rate Rule

Here, the central bank follows a Taylor (1993)-style interest rate rule:

$$\ln R_t = \ln R^* + \rho_\pi(\ln \pi_t - \ln \pi) + \rho_y(\ln Y_t - \ln Y) + e_t \tag{18}$$

where Y_t is aggregate real output, given by $Y_t = Y_{ct} + q_t Y_{dt}$. R^*, π, Y are steady-state interest rate, inflation and aggregate output respectively, and $e_t \sim N(0, \sigma_e^2)$ is a shock to monetary policy.

2.5.2 Ramsey-Optimal Monetary Policy

Alternatively, suppose that the central bank sets its policy according to the solution to a Ramsey problem, as in Levin et al. (2006), Khan et al. (2003), Siu (2004), Schmitt-Grohé and Uribe (2004), among others. The central bank's problem is to maximize the representative household's expected lifetime utility, Eq. (1), subject to the households Euler equations and constraints, Eqs. (3)–(7), price setting behavior of reoptimizing firms, Eq. (14), and market clearing conditions, Eqs. (21)–(23). The resulting first-order conditions, along with the equations characterizing firm and household optimization and market clearing conditions, give the solution of the model under the Ramsey-optimal monetary policy. The Ramsey problem is laid out in detail in Appendix B, and the equations characterizing the Ramsey equilibrium presented in Appendix C.

2.6 Aggregation and Equilibrium

Aggregation follows familiar steps from the DNK literature. Integrating both sides of the intermediate goods production technology, Eq. (12), gives

$$\int_0^1 Y_{jt}(i) = \int_0^1 A_{jt} N_{jt}(i) di = A_{jt} N_{jt} \tag{19}$$

where $N_{jt} = \int_0^1 N_{jt}(i) di$. Substituting for $Y_{jt}(i)$ in Eq. (19) using the demand function, Eq. (11), delivers

$$\underbrace{\left[\int_0^1 \left(\frac{P_{jt}(i)}{P_{jt}} \right)^{-\varepsilon_j} di \right]}_{s_{jt}} Y_{jt} = A_{jt} N_{jt} \tag{20}$$

where s_{jt} captures the inefficiencies associated with price dispersion arising from the Calvo (1983)-style staggered price reoptimization. Recall that at time t, only a fraction $1 - \omega_j$ of intermediate good producers are afforded the opportunity to reoptimize their prices.

The definition of a (recursive) equilibrium is fairly standard and is omitted for the sake of brevity. The market clearing conditions are:

$$Y_{ct} = C_t \qquad \text{Nondurables} \tag{21}$$

$$Y_{dt} = D_t - (1 - \delta) D_{t-1} \qquad \text{Durables} \tag{22}$$

$$N_t = N_{ct} + N_{dt} \qquad \text{Labor} \tag{23}$$

The equations characterizing equilibrium, including transformations to render nominal magnitudes stationary, are collected in Appendix A.

3 Estimation and Simulation

Many of the model's parameters are estimated via maximum likelihood. Impulse-responses are, then, generated. The goal is to see whether the model can produce Pigou cycles, meaning a boom in economic activity following receipt of a news shock. A forecast error variance decomposition is performed so as to

Table 1: Calibrated Parameters

Parameter	Value	Target	Value
β	0.99	Annual real interest rate	4%
α	0.77	Durables share of output	0.25
σ	1	Labor supply elasticity	1
υ	0.94	Steady state labor	$\frac{1}{3}$
ε_c, ε_d	8	Steady state markup	15%
π	1.01	Annual steady state inflation rate	4%

Table 2: Data Description

Model Variable	Data Counterpart
Y_t	Real Per Capita Gross Domestic Product
Y_{ct}	Real Per Capita Nondurable Consumption plus Services
Y_{dt}	Real Per Capita Durable Goods Consumption
R_t	Federal Funds Rate
π_t	GDP deflator

evaluate the importance of news shocks in accounting for aggregate fluctuations.

3.1 Estimation

As in Ireland (2001), among others, some parameters are difficult to estimate because they have very little effect on the likelihood. The parameters set based on *a priori* information are summarized in Table 1. The elasticity of substitution between intermediate goods is chosen based on evidence from Monacelli (2009). The remaining parameters/targets are fairly self-explanatory and/or standard in the literature.

The remaining parameters are estimated via maximum likelihood as in McGrattan (1994) and Hamilton (1994). Estimation requires casting the model in a state space representation. The five variables appearing in the observation equation are: nondurable goods output, Y_{ct}; durable goods output, Y_{dt}; aggregate output, Y_t; the nominal interest rate, R_t; and the inflation rate, π_t. The model is estimated using U.S. data over the period 1956Q3–2009Q4.[2]

The estimation results are summarized in Table 3. The elasticity of substitution between durables and nondurables, η, is 0.19 which means that these goods are complements in utility. The nondurable good sector has a higher probability of not reoptimizing prices than the durable sector. The estimates of ω_c

[2]The Federal funds rate is only available starting 1956Q3.

Table 3: Maximum Likelihood Estimation and Standard Error (in parentheses)

Parameter	Description	Estimate
δ	depreciation rate	0.0709
		(0.0038)
η	elasticity of substitution between nondurables and durables	0.1891
		(0.0135)
ω_c	nominal rigidity in nondurable sector	0.8259
		(0.0089)
ω_d	nominal rigidity in durable sector	0.7854
		(0.0286)
ρ_y	policy reaction to output	0.3126
		(0.0375)
ρ_π	policy reaction to inflation	2.5062
		(0.2099)
ρ_c	persistence of technology shock in nondurable sector	0.9083
		(0.0252)
ρ_d	persistence of technology shock in durable sector	0.4557
		(0.0396)
p	periods between signal and realization of productivity	4
$\sigma_{\xi c}$	standard deviation of nondurable sector news shock	0.0350
		(0.0025)
$\sigma_{\zeta c}$	standard deviation of nondurable sector technology shock	0.0339
		(0.0030)
$\sigma_{\xi d}$	standard deviation of durable sector news shock	0.0189
		(0.0019)
$\sigma_{\zeta d}$	standard deviation of durable sector technology shock	0.0747
		(0.0113)
σ_e	standard deviation of monetary shock	0.0076
		(0.0009)
log-likelihood		−3428.94

and ω_d imply that the nondurable goods prices are reoptimized, on average, every $5\frac{3}{4}$ quarters compared to $4\frac{2}{3}$ quarters for durable goods prices. These frequencies are consistent with the typical value estimated in the DNK literature. The policy parameters on inflation and output are not far from those estimated by Taylor (1993) and Clarida et al. (2000).

For the current paper, the more interesting parameters are those governing the news and contemporaneous shocks in the two sectors. In the nondurable sector, the standard deviation of news shocks is just slightly greater than that of the contemporaneous shocks. In the durable good sector, the standard deviation of the news shock is just 25% that of the contemporaneous shock. By this metric, news shocks are important sources of economic fluctuations.

Another parameter of interest is the number of periods between observing a news shock and when it affects productivity. This parameter is obtained by estimating the model with different lags. The lag that maximizes the log likelihood is 4 quarters.

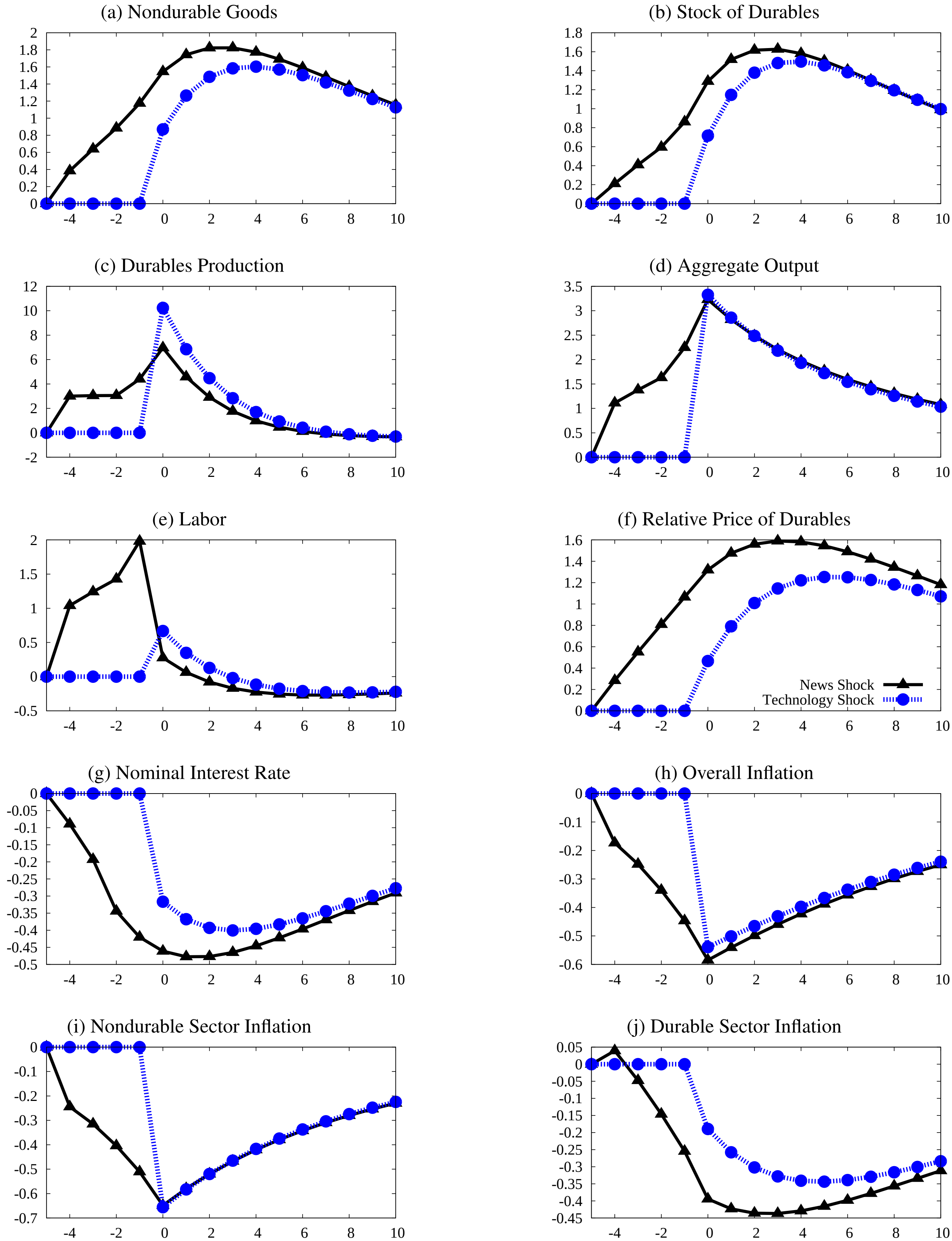
The parameter estimates are not particularly sensitive to the sample period. Estimates over three subsamples are presented in Appendix D. One split is in 1983-84, corresponding to the end of the so-called "Great Inflation." As seen in Table 6, overall, the parameter estimates are quite similar to those presented in Table 3.

Table 6 also provides estimates for the "Great Inflation" period, 1963Q1-1983Q4. Here, there are some differences. Of note are: the smaller estimated value of ω_d, the probability of price non-reoptimization in the durable goods sector, meaning that there is less price inertia in the durable goods sector; the larger values of ρ_c and ρ_d, the autoregressive parameters on the technology shocks in the two sectors; and the smaller value of $\sigma_{\zeta d}$, the standard deviation of the contemporaneous shock to durable sector productivity. Even for this subsample, the parameters are reasonably similar to the benchmark estimates.

3.2 Impulse-Responses

Figure 1 presents impulse-responses for: (a) a nondurable sector news shock received at time $t = -4$, and so coming into effect at $t = 0$; and (b) a nondurable sector contemporaneous shock received at $t = 0$. Both shocks are positive one standard deviation events, and the responses are expressed as percentage deviations from steady state. From time $t = 0$ forward, the effects for the two shocks are quite similar in

Figure 1: Responses to Nondurable Good Sector News Shock and Technology Shock



both shape and magnitude. However, under a news shock, variables move in advance of the realization of the shock at $t = 0$. Of particular interest is the fact that a nondurable sector news shocks leads to a boom in economic activity, manifested in both sectors, and so in employment and aggregate output. Observing a positive response of macroeconomic variables to a news shock has been an important component of the Pigou cycle literature. The logic works as follows: The news shock implies that, in the future, the marginal cost of producing nondurables will be lower. Owing to the nominal rigidities, intermediate goods firms are forward-looking and set their current price (if they are able to adjust it) based on current and future expected marginal costs. Consequently, nondurable intermediate goods producers start lowering their prices in advance of the news shock realization; see Figure 1i. Households, then, purchase more nondurables prior to the shock. Owing to the complementarity between durables and nondurables, households also wish to build up their stock of durables. As a result, the relative price of durables rises; consequently, so does the production of durables. While this is a large part of the story, monetary policy also plays an important role as explained in Section 4.2.

The effects of a durable sector news shock and contemporaneous shock are presented in Figure 2. Again, the news shock is observed at $t = -4$ and realized at $t = 0$ while the contemporaneous shock occurs at $t = 0$. As above, the shocks are positive, one standard deviation events. While the paths of the variables are reasonably similar starting at $t = 0$, the congruence is less pronounced than for nondurable sector shocks, even accounting for the fact that a one standard deviation news shock is roughly $\frac{1}{4}$ the size of the contemporaneous shock. Concentrating on the effects of the news shock, while the nondurable sector booms immediately, the durable sector does not. In fact, two periods prior to the realization of the shock, durable sector output is below control while in the subsequent period it rises above control. The strongest effect of the durable sector news shock is at time $t = 0$ when the news shock is realized. A similar pattern is observed with respect to aggregate output and labor. What is going on in this case is that households are willing to delay some of their purchases of durables until the price of durables falls – which coincides with the improvement in durable sector productivity. Consequently, households initially draw down their stock of durables. To smooth their utility, households boost their consumption of nondurables. Similar results are obtained in Beaudry and Portier (2004).

Finally, the responses to a monetary policy shock can be found in Figure 3. Perhaps the most striking

Figure 2: Responses to Durable Good Sector News Shock and Technology Shock

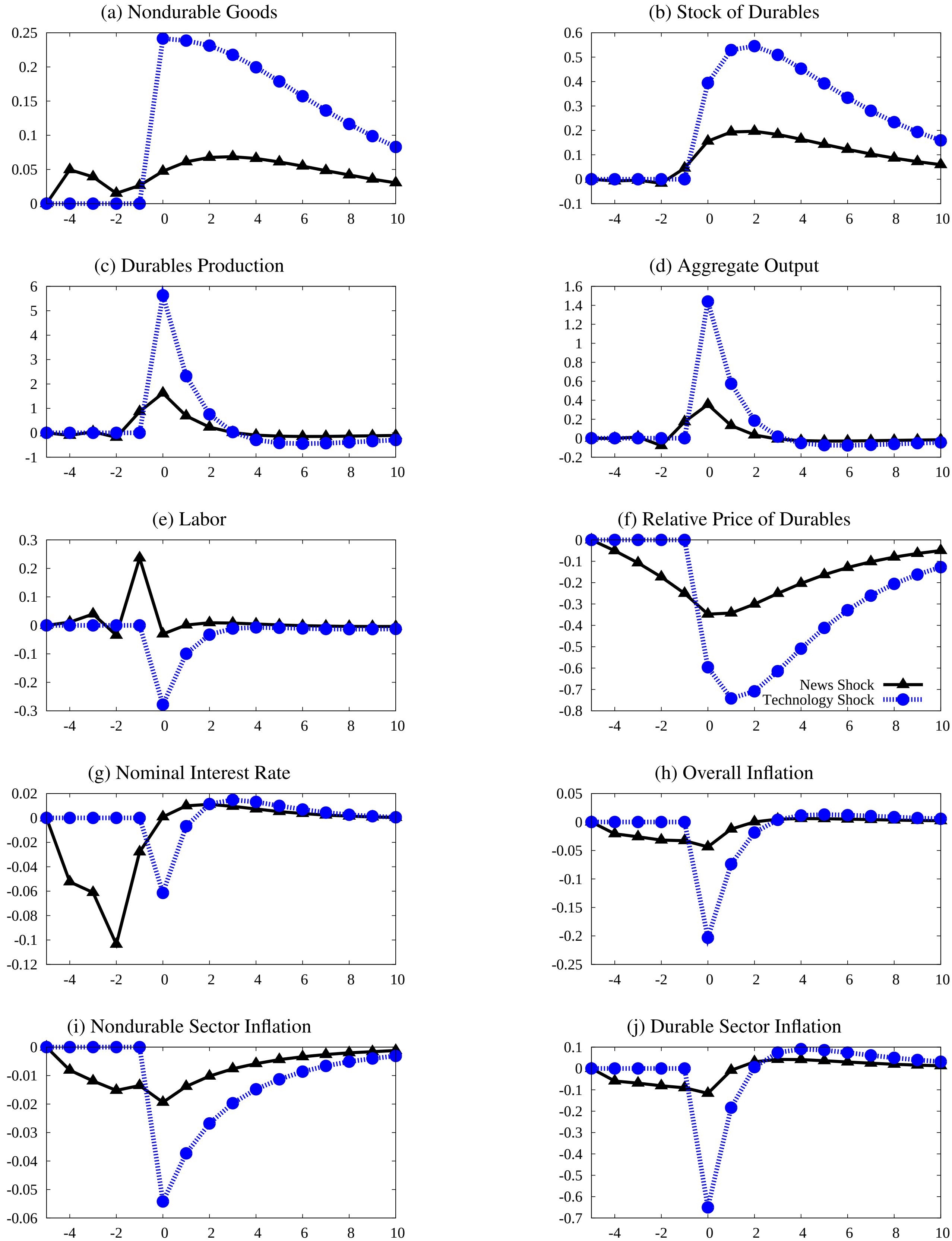
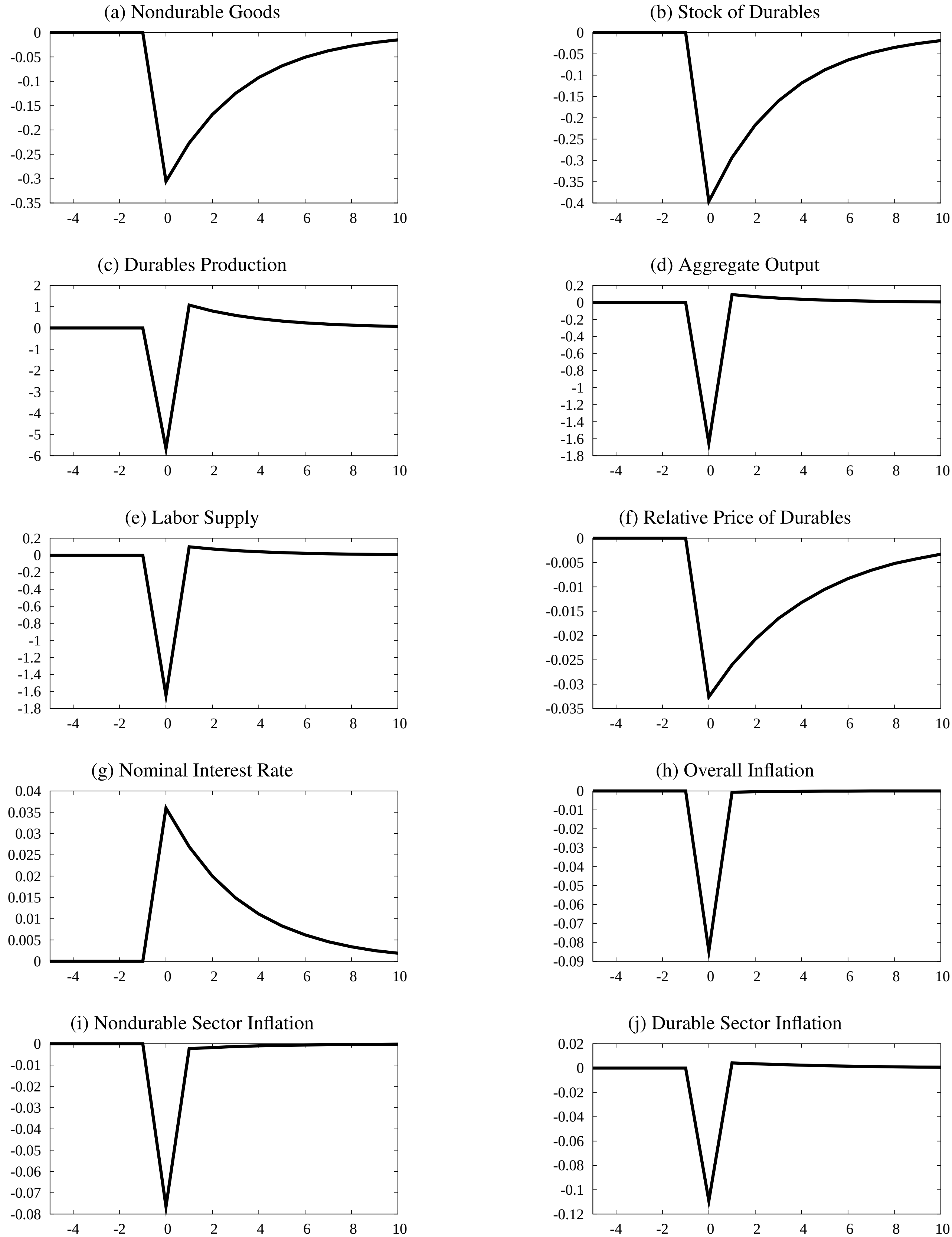


Figure 3: Responses to a Monetary Policy Shock



features of these impulse-responses are the small magnitudes of the responses, and that most of the dynamics plays out in the period of the shock.

In summary, while the economy exhibits Pigou cycles in response to nondurable sector news shocks, such cycles fail to materialize following a durable sector news shock.

3.3 Variance Decomposition

Another means of assessing the importance of news shocks is to decompose the variation in various series into the fraction attributable to the five shocks in the model. Table 4 report the forecast error variance decomposition, at different time horizons, for key variables from the model.

The bulk of the variation in *all* series – aggregate output, nondurable sector output, durable sector output, the interest rate and the inflation rate – are driven by shocks to nondurable sector productivity, regardless of the time horizon. At very short horizons (2 quarters), these shocks contribute between 67% (durable sector output) to 95% (nominal interest rate) of variability. At medium horizons (8 to 12 quarters), the importance of these shocks rises to between 75% (durable sector output) to well over 90% for the other aggregate series.

At short horizons, the contemporaneous nondurable sector shock is the single most important source of fluctuations in the benchmark economy: from just over 60% in the durable sector to over 80% for the nominal interest rate. At longer horizons, the nondurable sector news shock's contribution to aggregate fluctuations rises. At the longest horizons, this news shocks becomes the most important source of fluctuations, contributing well over 50% of overall variation – with the exception of the durable sector where it contributes just over 30%.

Monetary policy shocks have their strongest influence in the durable good sector, particularly at short horizons where they make up around 15% of the variability of this series. What is happening here is that movements in the nominal interest rate get translated into changes in the real interest rate which, in turn, generate fluctuations in the user cost of durables, as defined in Eq. (9). At first blush, it may seem odd that monetary policy shocks have little effect on the variability of the nominal interest rate. This result can be explained with reference to Figure 3 which reports impulse-responses to a monetary policy shock. The responses of the economy to monetary policy shocks – including the nominal interest rate – are quite

Table 4: Forecast Error Variance Decomposition

Quarters Ahead	2	4	8	12	20	∞
Aggregate Output						
Nondurables news shocks	9.79	16.50	34.53	41.55	46.74	51.65
Nondurables contemporary shocks	67.91	67.50	55.65	50.70	47.00	43.50
Durables news shocks	0	0.03	0.18	0.18	0.17	0.16
Durables contemporary shocks	10.04	7.35	4.49	3.54	2.86	2.22
Monetary policy shocks	12.26	8.62	5.15	4.03	3.22	2.48
Nondurable Sector Output						
Nondurables news shocks	16.62	23.03	38.60	46.22	51.87	56.36
Nondurables contemporary shocks	73.50	71.29	58.59	51.82	46.71	42.61
Durables news shocks	0.15	0.08	0.06	0.07	0.07	0.06
Durables contemporary shocks	4.10	2.70	1.52	1.11	0.83	0.62
Monetary policy shocks	5.62	2.90	1.23	0.78	0.53	0.35
Durable Sector Output						
Nondurables news shocks	6.55	10.33	22.76	26.74	29.52	32.50
Nondurables contemporary shocks	61.34	61.50	53.81	51.22	49.41	47.48
Durables news shocks	0.01	0.09	0.65	0.80	0.90	1.02
Durables contemporary shocks	16.48	14.60	11.90	11.13	10.60	10.04
Monetary policy shocks	15.62	13.49	10.89	10.11	9.56	8.96
Nominal Interest Rate						
Nondurables news shocks	13.02	29.30	44.71	50.65	55.06	58.75
Nondurables contemporary shocks	82.06	67.10	53.44	48.07	44.03	40.62
Durables news shocks	2.26	2.34	1.27	0.89	0.64	0.45
Durables contemporary shocks	1.85	0.83	0.36	0.24	0.17	0.11
Monetary policy shocks	0.81	0.44	0.21	0.15	0.10	0.07
Inflation Rate						
Nondurables news shocks	11.50	21.08	39.53	46.38	51.34	55.74
Nondurables contemporary shocks	78.68	72.68	57.07	51.10	46.75	42.86
Durables news shocks	0.15	0.20	0.21	0.18	0.15	0.12
Durables contemporary shocks	8.32	5.22	2.77	2.03	1.54	1.11
Monetary policy shocks	1.35	0.82	0.43	0.31	0.23	0.17

small, particularly when compared to responses to real shocks as reported in Figures 1 and 2. Further, the effects of a monetary policy shock are generally relatively small and short-lived, factors that account for the small variance contribution of these shocks reported in Table 4.

In summary, at short horizons, the majority of the variation in macro time series are driven by contemporaneous shocks to nondurable sector productivity. At longer horizons, the importance of this shock declines while that of nondurable sector news shocks rises. At very long horizons, nondurable sector news shocks account for over half of the variation of these time series, with the exception of durable sector output where it still contributes nearly $\frac{1}{3}$ of total variation.

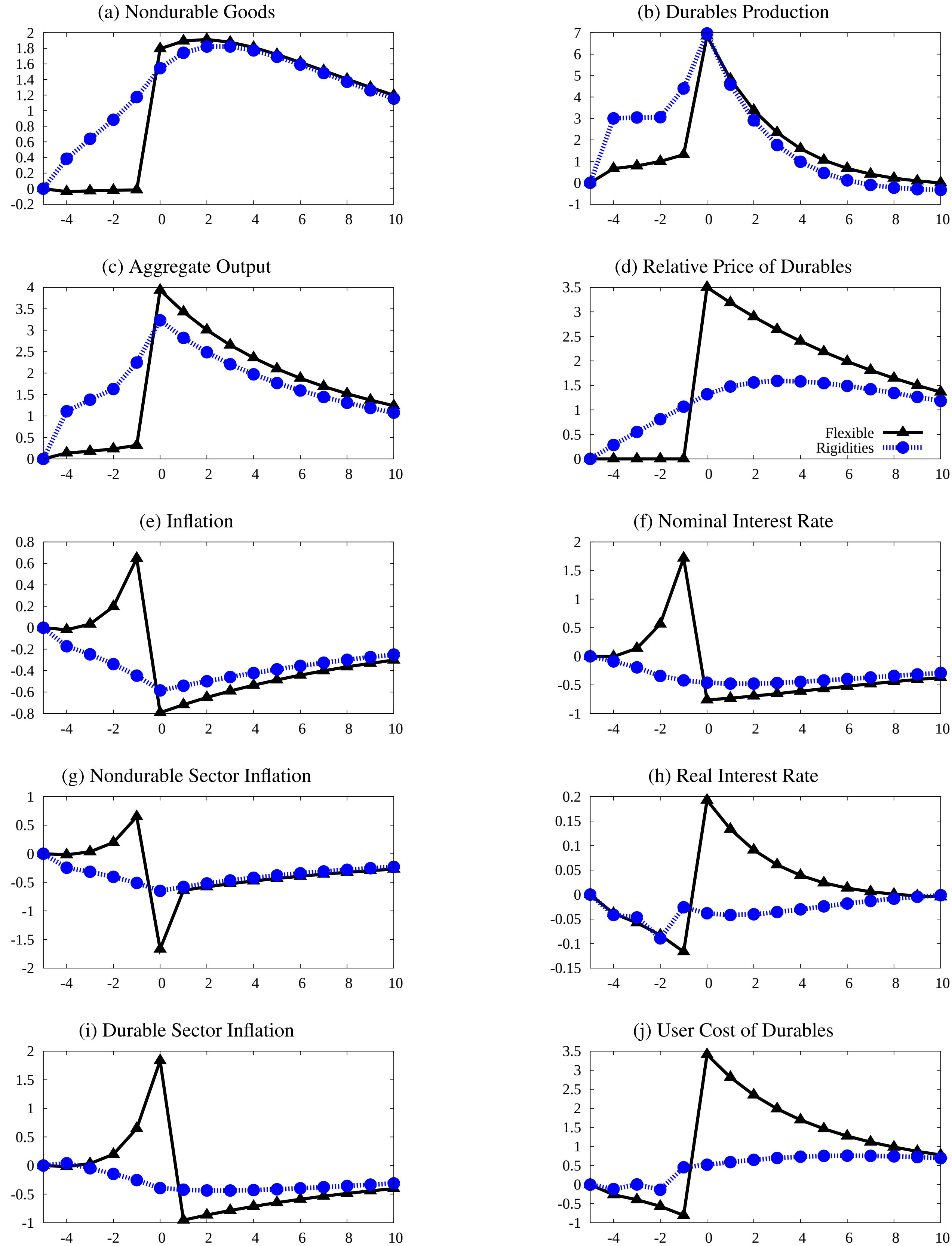
4 The Sources of Pigou Cycles

As seen in Figure 1, Pigou cycles arise in response to nondurable sector news shocks (but not durable sector news shocks, as reported in Figure 2). What model features account for the Pigou cycles? This section assesses the roles of nominal rigidities, monetary policy, and the cash-in-advance constraint.

4.1 Nominal Rigidities

Figure 4 traces out impulse-responses following a nondurable sector news shock for the benchmark estimated model, and for a version of the model that allows prices to be fully flexible (by setting the non-reoptimization probabilities, ω_c and ω_d, to zero). Flexible prices mutes the response of nondurables production, leading to a slight bust in that sector. With sticky prices, nondurable intermediate good producers are forward-looking, setting their prices based on current and expected future marginal costs. Since the news shock implies a fall in future marginal costs, with sticky prices the price of nondurables starts falling immediately. In contrast, under flexible prices the price of nondurables rises leading up to the shock, then falls sharply; see Figure 4g. The dynamics of durable sector prices generally follows that of nondurables prices. When prices are sticky, the price of durables falls whereas when prices are flexible, durables prices rise prior to the realization of the shock, then fall sharply; see Figure 4i. Under flexible prices, there is virtually no change in the relative price of durables leading up to the realization of the news shock, at which time the relative price rises sharply; see Figure 4d.

Figure 4: Responses to a Nondurable Sector News Shock in the Model with and without Nominal Rigidities



Earlier, Eq. (8) showed that with long lived durables, this relative price is an important determinant of nondurable consumption, an observation also made by Barsky et al. (2007). In other words, the role of nominal price rigidities is to generate movements in the relative price of durables that do not occur under flexible prices.

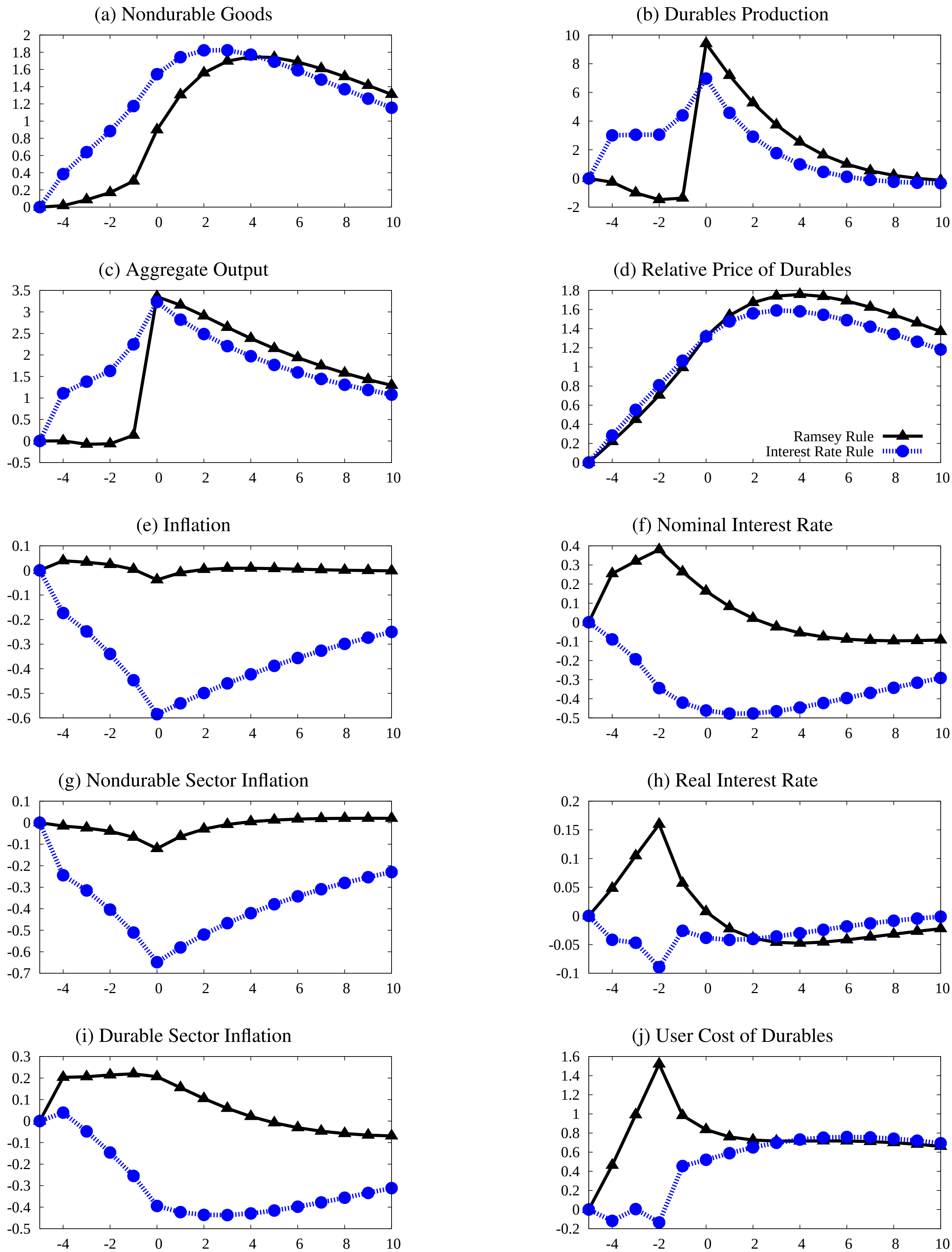
4.2 Monetary Policy

Rather than the estimated interest rate rule, suppose that monetary policy is conducted according to the precepts of the Ramsey rule introduced in section 2.5.2. Figure 5 compares the responses to a news shock in the benchmark model with that obtained under the Ramsey-optimal policy. The key result is that the Ramsey-optimal policy does not lead to Pigou cycles. In particular, in the periods leading up to the realization of the nondurable sector news shock, production of durables falls under the Ramsey policy while that of nondurables rises slightly (both rise under the estimated interest rate rule); the net effect is a decline in aggregate output.

To explain why the Ramsey policy does not generate Pigou cycles, it is necessary to reexamine some implications of the Ramsey policy. Recall that the Ramsey problem seeks to maximize expected lifetime utility of the representative agent, subject to private optimization conditions and constraints. Having offset the distortions associated with monopoly pricing with a production subsidy, there are two remaining distortions. The first is associated with variation in the within-sector relative prices of intermediate goods. This distortion is minimized by setting (average) inflation to zero. The second is the distortion to consumption and labor owing to the cash-in-advance constraint. The standard condition to offset this distortion is to deflate at the real interest rate. Since the Ramsey policy delivers, on average, an inflation rate close to zero, it seems that the welfare consequences of within-sector price dispersion is more important than those of the cash-in-advance constraint.

So, in the face of a nondurable sector news shock, the Ramsey-optimal policy will seek to dampen the responses of inflation in the two sectors. Achieving this goal works through a round about route. The central bank must depress the production and purchase of durable goods in order to dampen the response of nondurables, a result that follows from the complementarity between durables and nondurables. Purchases of durables is suppressed by raising the nominal interest rate which, in turn, increases the real

Figure 5: Responses to Nondurable Sector News Shock under Ramsey Policy and Estimated Interest Rate Rule



interest rate, and so the user cost of durables, defined in Eq. (9).

The policy response under the Ramsey policy stands in sharp contrast to that of the estimated interest rate rule. Under the estimated rule, the nominal interest rate *falls* following the nondurable sector news shock. As a result, the real interest rate falls below control, as does the user cost of durables. In other words, Pigou cycles arise under the estimated interest rate rule precisely because the central bank accommodates such cycles.

4.3 Cash-in-advance Constraint

To evaluate the role played by the cash-in-advance constraint, suppose that money demand is motivated by money-in-the-utility function. More specifically, preferences are replaced by

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t, D_t, N_t, \frac{M_t}{P_t}\right), \quad 0 < \beta < 1 \tag{24}$$

where

$$U(C,D,N,M/P) = \ln\left[(1-\alpha)^{\frac{1}{\eta}} C^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} D^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} - \upsilon \frac{N^{1+\sigma}}{1+\sigma} + \varphi \ln\left(\frac{M}{P}\right). \tag{25}$$

This formulation isolates the deleterious effects of within-sector relative price distortions by abstracting from the transactions distortion introduced by the cash-in-advance constraint.

Estimates of the money-in-the-utility function model are presented in Table 5.[3] The estimates are broadly similar to those obtained for the benchmark model. Focusing on the technology shock processes, the autoregressive parameter in the nondurable sector is higher (0.99 compared to 0.91) while that in the durable sector is lower (0.3 versus 0.46). While the standard deviation of the nondurable sector news shock is virtually the same, that of the contemporaneous shock is somewhat lower (0.26 as opposed to 0.034). In the durable sector, news shocks exhibit a bit less volatility (0.016 compared to 0.019) while contemporaneous shocks are much less variable (0.04 rather than 0.075).

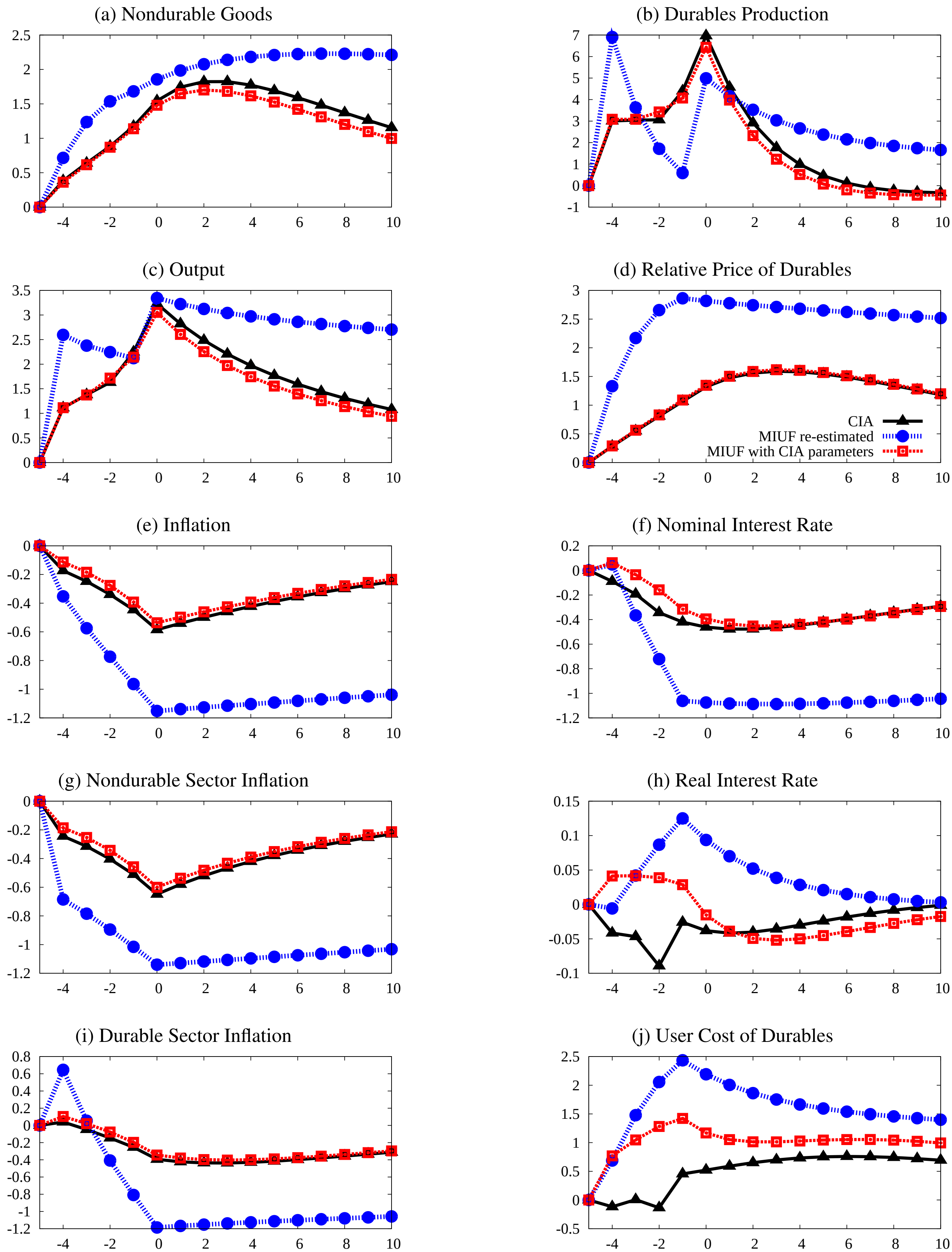
As reported in Figure 6, qualitatively, the results are little changed under the above specification of money demand. In particular, the economy continues to experience a boom following a nondurable

[3]Identical results are obtained by specifying money demand as being proportional to nominal purchases as in Barsky et al. (2007). The reason why the results are identical is that, in both cases, money does not affect the remaining equations characterizing equilibrium of the model.

Table 5: Maximum Likelihood Estimation and Standard Error (in parentheses): Money-in-the-Utility Function

Parameter	Description	Estimate
δ	depreciation rate	0.0636
		(0.0086)
η	elasticity of substitution between nondurables and durables	0.2201
		(0.0499)
ω_c	nominal rigidity in nondurable sector	0.8544
		(0.0132)
ω_d	nominal rigidity in durable sector	0.5848
		(0.4656)
ρ_y	policy reaction to output	0.2368
		(0.0086)
ρ_π	policy reaction to inflation	1.6299
		(0.1538)
ρ_c	persistence of technology shock in nondurable sector	0.9901
		(0.1271)
ρ_d	persistence of technology shock in durable sector	0.3001
		(0.3463)
p	periods between signal and realization of productivity	4
$\sigma_{\xi c}$	standard deviation of nondurable sector news shock	0.0352
		(0.0034)
$\sigma_{\zeta c}$	standard deviation of nondurable sector technology shock	0.0260
		(0.0067)
$\sigma_{\xi d}$	standard deviation of durable sector news shock	0.0157
		(0.0042)
$\sigma_{\zeta d}$	standard deviation of durable sector technology shock	0.0401
		(0.0484)
σ_e	standard deviation of monetary shock	0.0052
		(0.0003)
log-likelihood		-3408.99

Figure 6: Responses to Nondurable Sector News Shock: Money-in-the-Utility Function (MIUF) compared to Cash-in-advance Constraint (CIA)



sector news shock, with these responses being attenuated relative to those obtained under the cash-in-advance constraint. Interestingly, with money-in-the-utility function, the durable sector booms prior to the realization of the news shock despite the fact that both the real interest rate and user cost of durables rise.

Figure 6 also gives impulse-responses for the money-in-the-utility function model using the parameter estimates for the cash-in-advance model which allows a direct comparison of the two motives for money demand. With two notable exceptions, the paths for the money-in-the-utility function and cash-in-advance models move very closely together. One exception is the real interest rate which *rises* prior to the realization of the shock under money-in-the-utility function whereas it *falls* under cash-in-advance. In this, the money-in-the-utility function using the cash-in-advance parameter estimates behaves somewhat more like the money-in-the-utility function results when the parameters are all re-estimated. Given the different behavior of the real interest rate, it should not be surprising that the user cost of durables also differs. The money-in-the-utility function specification using cash-in-advance parameter estimates lies smack between those for the two estimated models.

The differences in the two money-in-the-utility function impulse-responses reflects the influence of the different parameter estimates (that is, between the estimated money-in-the-utility function model and the cash-in-advance model). While the specific time paths are somewhat sensitive to the parameter estimates, it is nonetheless the case that both sets of estimates still deliver Pigou cycles.

5 Conclusion

The chief finding of this paper is that monetary policy can lead to Pigou cycles. More specifically, a nondurable sector news shock – a signal of a future productivity improvement – leads to a general expansion in economic activity. The particular monetary policy analyzed above is an interest rate rule à la Taylor (1993), estimated from U.S. data. Sluggish price-setting behavior along the lines of Calvo (1983) imply that intermediate good producers are forward-looking in their pricing behavior. In the aftermath of a nondurable sector news shock, nondurable sector intermediate good producers lower their prices in advance of the realization of the shock because they set their price based on expected future marginal cost which has fallen. Households increase their purchases of nondurables as a result of this price decline. They also boost spending on durables due to a complementarity in utility between durables and nondurables.

Monetary policy plays an important role in the dynamics described above. In particular, the nondurable sector news shock pushes down inflation, leading the central bank of lower the nominal interest rate. As a result, both the real interest rate and user cost of durables also fall. Contrast this dynamic with that obtained under the Ramsey-optimal policy. In order to minimize within-sector price dispersion, the central bank raises the nominal interest rate, and so the real interest rate and user cost of durables. The effect is to depress purchases of durables, and via the complementarity between durables and nondurables, purchases of nondurables as well. Under the Ramsey policy, economic activity declines following a nondurable sector news shock, recovering only after the direct effects of the shock on productivity are realized.

The paper also makes a contribution to the empirics of news shocks. Specifically, the estimated parameters of the technology process reveal that in the nondurable good sector, news shock variability is almost the same as that of contemporaneous shocks; in the durable good sector, news shocks exhibit $\frac{1}{4}$ of the volatility of contemporaneous shocks. Further evidence on the importance of news shocks in economic fluctuations is reported obtained from a forecast error decomposition. While nondurable sector news shocks account for a small – but non-negligible – fraction of the variability of macroaggregates in the short term, in the medium and long terms, these shocks account for roughly half of aggregate output, nominal interest rate and inflation variability.

A Summary of Equations Describing the Model Equilibrium

$$
\begin{aligned}
q_t U_c(C_t,D_t,N_t) &= U_d(C_t,D_t,N_t) + \beta E_t\left\{q_{t+1}U_c(C_{t+1},D_{t+1},N_{t+1})(1-\delta)\right\} \\
\frac{U_n(C_t,D_t,N_t)}{W_t} &= \beta E_t\left\{R_t \frac{U_n(C_{t+1},D_{t+1},N_{t+1})}{W_{t+1}}\right\} \\
-\frac{U_n(C_t,D_t,N_t)}{W_t} &= \beta E_t\left\{\frac{U_c(C_{t+1},D_{t+1},N_{t+1})}{P_{c,t+1}}\right\} \\
P1_{j,t} &= \omega_j\beta\left(\frac{\pi_{t+1}}{\pi}\right)^{\varepsilon_j} P1_{j,t+1} + U_c(C_t,D_t,N_t)MC_{j,t}Y_{j,t}\hat{P}_{j,t}^{\varepsilon_j-1}\hat{P}_{c,t} \\
P2_{j,t} &= \omega_j\beta\left(\frac{\pi_{t+1}}{\pi}\right)^{\varepsilon_j-1} P2_{j,t+1} + U_c(C_t,D_t,N_t)Y_{j,t}\hat{P}_{j,t}^{\varepsilon_j-1} \\
\hat{P}_{j,t}^{*} &= \frac{P1_{j,t}}{P2_{j,t}} \\
\hat{P}_{j,t} &= \left[(1-\omega_j)(\hat{P}_{j,t}^{*})^{1-\varepsilon_j} + \omega_j(\hat{P}_{j,t-1}\pi/\pi_t)^{1-\varepsilon_j}\right]^{\frac{1}{1-\varepsilon_j}} \\
(\hat{P}_{c,t}C_t + \hat{P}_{d,t}I_t)/(C_t+I_t) &= 1 \\
A_{c,t}N_{c,t} &= s_{c,t}C_t \\
A_{d,t}N_{d,t} &= s_{d,t}(D_t-(1-\delta)D_{t-1}) \\
s_{j,t} &= (1-\omega_j)\left(\frac{\hat{P}_{j,t}^{*}}{\hat{P}_{j,t}}\right)^{-\varepsilon_j} + \omega_j\left(\frac{\pi}{\pi_{j,t}}\right)^{-\varepsilon_j} s_{j,t-1} \\
N_t &= N_{c,t} + N_{d,t} \\
I_t &= D_t - (1-\delta)D_{t-1} \\
q_t &= \hat{P}_{d,t}/\hat{P}_{c,t} \\
\ln(A_{j,t}) &= \rho_j \ln(A_{j,t-1}) + \varepsilon_{j,t-p} + \zeta_{j,t}
\end{aligned}
$$

B The Ramsey Problem

$$
\begin{aligned}
&\max E_0 \sum_{t=0}^{\infty} \beta^t \Bigg\{ \ln(X_t) - \upsilon\frac{N_t^{1+\sigma}}{1+\sigma} \\
&+ \lambda_{1t}\left(\upsilon N_t^{\sigma} - \hat{W}_t\lambda_t\right) \\
&+ \lambda_{2t}\left(X_t - \left[(1-\alpha)^{\frac{1}{\eta}} C_t^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} D_t^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}\right)
\end{aligned}
$$

$$+\lambda_{3t}\left(X_t^{\frac{1-\eta}{\eta}}(1-\alpha)^{\frac{1}{\eta}}C_t^{-\frac{1}{\eta}}-\lambda_t-\gamma_t\right)$$
$$+\lambda_{4t}\left(X_t^{\frac{1-\eta}{\eta}}\alpha^{\frac{1}{\eta}}D_t^{-\frac{1}{\eta}}+\beta(1-\delta)E_t\left\{(\lambda_{t+1}+\gamma_{t+1})q_{t+1}\right\}-q_t\{\lambda_t+\gamma_t\}\right)$$
$$+\lambda_{5t}\left(1-\beta E_t\left\{\frac{R_t}{\pi_{c,t+1}}\frac{\lambda_{t+1}}{\lambda_t}\right\}\right)$$
$$+\lambda_{6t}\left(P1_{c,t}-\omega_c\beta(\frac{\pi_{t+1}}{\pi})^{\varepsilon_c}P1_{c,t+1}+\lambda_t MC_{c,t}Y_{c,t}\hat{P}_{c,t}^{\varepsilon_j}\right)$$
$$+\lambda_{7t}\left(P2_{c,t}-\omega_c\beta(\frac{\pi_{t+1}}{\pi})^{\varepsilon_c-1}P2_{c,t+1}+\lambda_t Y_{c,t}\hat{P}_{c,t}^{\varepsilon_j-1}\right)$$
$$+\lambda_{8t}\left(\hat{P}_{c,t}^{*}-\frac{P1_{c,t}}{P2_{c,t}}\right)$$
$$+\lambda_{9t}\left(\hat{P}_{c,t}^{1-\varepsilon_c}-\left[(1-\omega_c)(\hat{P}_{c,t}^{*})^{1-\varepsilon_c}+\omega_c(\hat{P}_{c,t-1}\pi/\pi_t)^{1-\varepsilon_c}\right]\right)$$
$$+\lambda_{10t}\left(\pi_{c,t}-\pi_t\hat{P}_{c,t}/\hat{P}_{c,t-1}\right)$$
$$+\lambda_{11t}\left(P1_{d,t}-\omega_d\beta\left(\frac{\pi_{t+1}}{\pi}\right)^{\varepsilon_d}P1_{d,t+1}-\lambda_t MC_{d,t}I_t\hat{P}_{d,t}^{\varepsilon_d-1}\hat{P}_{c,t}\right)$$
$$+\lambda_{12t}\left(P2_{d,t}-\omega_d\beta\left(\frac{\pi_{t+1}}{\pi}\right)^{\varepsilon_d-1}P2_{d,t+1}-\lambda_t I_t\hat{P}_{d,t}^{\varepsilon_d-1}\right)$$
$$+\lambda_{13t}\left(\hat{P}_{d,t}^{*}-\frac{P1_{d,t}}{P2_{d,t}}\right)$$
$$+\lambda_{14t}\left(\hat{P}_{d,t}^{1-\varepsilon_d}-\left[(1-\omega_d)(\hat{P}_{d,t}^{*})^{1-\varepsilon_d}+\omega_d(\hat{P}_{d,t-1}\pi/\pi_t)^{1-\varepsilon_d}\right]\right)$$
$$+\lambda_{15t}\left(\pi_{d,t}-\pi_t\hat{P}_{d,t}/\hat{P}_{d,t-1}\right)$$
$$+\lambda_{16t}\left((\hat{P}_{c,t}C_t+\hat{P}_{d,t}I_t)/(C_t+I_t)\right)$$
$$+\lambda_{17t}\left(s_{c,t}-(1-\omega_c)\left(\frac{\hat{P}_{c,t}^{*}}{\hat{P}_{c,t}}\right)^{-\varepsilon_c}-\omega_c\left(\frac{\pi}{\pi_{c,t}}\right)^{-\varepsilon_c}s_{c,t-1}\right)$$
$$+\lambda_{18t}\left(s_{d,t}-(1-\omega_d)\left(\frac{\hat{P}_{d,t}^{*}}{\hat{P}_{d,t}}\right)^{-\varepsilon_d}-\omega_d\left(\frac{\pi}{\pi_{d,t}}\right)^{-\varepsilon_d}s_{d,t-1}\right)$$
$$+\lambda_{19t}\left(MC_{c,t}-\frac{\hat{W}_t}{A_{c,t}}\right)$$
$$+\lambda_{20t}\left(MC_{d,t}-\frac{\hat{W}_t}{A_{c,t}}\right)$$
$$+\lambda_{21t}\left(s_{c,t}C_t-A_{c,t}N_{c,t}\right)$$
$$+\lambda_{22t}\left(s_{d,t}(D_t-(1-\delta)D_{t-1})-A_{d,t}N_{d,t}\right)$$
$$+\lambda_{23t}(I_t-D_t+(1-\delta)D_{t-1})$$
$$+\lambda_{24_t}(N_t-N_{ct}-N_{dt})$$

$$+\lambda_{25t}(q_t - \hat{P}_{d,t}/\hat{P}_{ct})$$

$$+\lambda_{26t}(\beta\{\frac{\lambda_{t+1}+\gamma_{t+1}}{\pi_{c,t}}\}-\lambda_t)\Bigg\}$$

C First Order Conditions of the Ramsey Problem

$$C_t: \quad -\lambda_{2t}X_t^{\frac{1}{\eta}}(1-\alpha)^{\frac{1}{\eta}}C_t^{-\frac{1}{\eta}} - \lambda_{3t}X_t^{\frac{1-\eta}{\eta}}(1-\alpha)^{\frac{1}{\eta}}(\frac{1}{\eta})C_t^{-\frac{1}{\eta}-1} - \lambda_{6t}\lambda_t MC_{ct}\hat{P}_{c,t}^{\varepsilon_c}$$

$$-\lambda_{7t}\lambda_t\hat{P}_{c,t}^{\varepsilon_c-1} + \lambda_{16t}(\hat{P}_{d,t}-\hat{P}_{c,t})I_t/(C_t+I_t)^2 + \lambda_{21}s_{c,t} = 0$$

$$D_t: \quad -\lambda_{2t}X_t^{\frac{1}{\eta}}\alpha^{\frac{1}{\eta}}D_t^{-\frac{1}{\eta}} - \lambda_{4t}X_t^{\frac{1-\eta}{\eta}}\alpha^{\frac{1}{\eta}}(\frac{1}{\eta})D_t^{-\frac{1}{\eta}-1} + \lambda_{22t}s_{d,t} - \beta\lambda_{22t+1}s_{d,t+1}(1-\delta)$$

$$-\lambda_{23t} + \beta\lambda_{23t+1}(1-\delta) = 0$$

$$I_t: \quad -\lambda_{11t}\lambda_t MC_{d,t}\hat{P}_{d,t}^{\varepsilon_d-1}\hat{P}_{c,t} - \lambda_{12t}\lambda_t\hat{P}_{d,t}^{\varepsilon_d-1} + \lambda_{16t}(\hat{P}_{c,t}-\hat{P}_{d,t})C_t/(C_t+I_t)^2 + \lambda_{23t} = 0$$

$$\lambda_t: \quad -\lambda_{1t}\hat{W}_t - \lambda_{3t} - \lambda_{4t}q_t + \frac{1}{\beta}\lambda_{4t-1}\beta(1-\delta)q_t + \lambda_{5t}\beta\frac{R_t}{\pi_{c,t+1}}\frac{\lambda_{t+1}}{\lambda_t^2} - \frac{1}{\beta}\lambda_{5t-1}\beta\frac{R_{t-1}}{\pi_{c,t}}\frac{1}{\lambda_{t-1}}$$

$$-\lambda_{6t}MC_{c,t}C_t\hat{P}_{c,t}^{\varepsilon_c} - \lambda_{7t}C_t\hat{P}_{c,t}^{\varepsilon_c-1} - \lambda_{11t}MC_{d,t}I_t\hat{P}_{d,t}^{\varepsilon_d-1}\hat{P}_{c,t} - \lambda_{12t}I_t\hat{P}_{d,t}^{\varepsilon_d-1} - \lambda_{26t} + \lambda_{26t-1}/\pi_{c,t} = 0$$

$$MC_{ct}: \quad -\lambda_{6t}\lambda_t C_t\hat{P}_{c,t}^{\varepsilon_c} + \lambda_{19t} = 0$$

$$MC_{dt}: \quad -\lambda_{11t}\lambda_t MC_{d,t}I_t\hat{P}_{d,t}^{\varepsilon_d-1}\hat{P}_{c,t} + \lambda_{20t} = 0$$

$$N_t: \quad -\upsilon N_t^{\sigma} + \lambda_{1t}\upsilon\sigma N_t^{\sigma-1} + \lambda_{24t} = 0$$

$$N_{ct}: \quad -\lambda_{21t}A_{ct} - \lambda_{24t} = 0$$

$$N_{dt}: \quad -\lambda_{22t}A_{dt} - \lambda_{24t} = 0$$

$$P1_{ct}: \quad \lambda_{6t} - \frac{1}{\beta}\lambda_{6t-1}\omega_c\beta\left(\frac{\pi_t}{\pi}\right)^{\varepsilon_c} - \frac{\lambda_{8t}}{P2_{c,t}} = 0$$

$$P1_{dt}: \quad \lambda_{11t} - \frac{1}{\beta}\lambda_{11t-1}\omega_d\beta\left(\frac{\pi_t}{\pi}\right)^{\varepsilon_d} - \frac{\lambda_{13t}}{P2_{d,t}} = 0$$

$$P2_{ct}: \quad \lambda_{7t} - \frac{1}{\beta}\lambda_{7t-1}\omega_c\beta(\frac{\pi_t}{\pi})^{\varepsilon_c-1} + \lambda_{8t}\frac{P1_{c,t}}{P2_{c,t}^2} = 0$$

$$P2_{dt}: \quad \lambda_{12t} - \frac{1}{\beta}\lambda_{12t-1}\omega_d\beta(\frac{\pi_t}{\pi})^{\varepsilon_d-1} + \lambda_{13t}\frac{P1_{d,t}}{P2_{d,t}^2} = 0$$

$$\hat{P}_{ct}: \quad -\lambda_{6t}\lambda_t MC_{c,t}C_t\hat{P}_{c,t}^{\varepsilon_c-1}\varepsilon_c - \lambda_{7t}\lambda_t C_t\hat{P}_{c,t}^{\varepsilon_c-2}(\varepsilon_c-1) + \lambda_{9t}(1-\varepsilon_c)(\hat{P}_{ct})^{-\varepsilon_c}$$

$$-\beta\lambda_{9t+1}\omega_c(\hat{P}_{c,t}\pi/\pi_t)^{1-\varepsilon_c}(1-\varepsilon_c)(\frac{1}{\hat{P}_{ct}}) - \lambda_{10t}\pi_t/\hat{P}_{c,t-1} + \beta\lambda_{10t+1}\pi_{t+1}\hat{P}_{c,t+1}/\hat{P}_{c,t}^2$$

$$-\lambda_{11t}\lambda_t MC_{d,t} I_t \hat{P}_{d,t}^{\varepsilon_d-1} - \lambda_{16t} C_t/(C_t+I_t) + \lambda_{17t}(\omega_c-1)\varepsilon_c \left(\frac{\hat{P}^*_{c,t}}{\hat{P}_{c,t}}\right)^{-\varepsilon_c} \frac{1}{\hat{P}_{c,t}} + \lambda_{25t}\frac{\hat{P}_{dt}}{\hat{P}^2_{ct}} = 0$$

$$\hat{P}_{dt}: \quad -\lambda_{12t}\lambda_t MC_{d,t} I_t \hat{P}_{d,t}^{\varepsilon_d-2}\hat{P}_{c,t}\varepsilon_d - \lambda_{12t}\lambda_t I_t \hat{P}_{d,t}^{\varepsilon_d-2}(\varepsilon_d-1) + \lambda_{14t}(1-\varepsilon_d)(\hat{P}_{dt})^{-\varepsilon_d}$$

$$-\beta\lambda_{14t+1}\omega_d(\hat{P}_{d,t}\pi/\pi_t)^{1-\varepsilon_d}(1-\varepsilon_d)(\frac{1}{\hat{P}_{dt}}) - \lambda_{15t}\pi_t/\hat{P}_{d,t-1} + \beta\lambda_{15t+1}\pi_{t+1}\hat{P}_{d,t+1}/\hat{P}^2_{d,t}$$

$$-\lambda_{16t} I_t/(C_t+I_t) + \lambda_{17t}(\omega_d-1)\varepsilon_d\left(\frac{\hat{P}^*_{d,t}}{\hat{P}_{d,t}}\right)^{-\varepsilon_d}\frac{1}{\hat{P}_{d,t}} + \frac{\lambda_{25t}}{\hat{P}_{ct}} = 0$$

$$\pi_t: \quad -\frac{1}{\beta}\lambda_{6t-1}\omega_c\beta P1_{ct}(\frac{\pi_t}{\pi})^{\varepsilon_c}\frac{\varepsilon_c}{\pi_t} - \frac{1}{\beta}\lambda_{7t-1}\omega_c\beta P2_{ct}(\frac{\pi_t}{\pi})^{\varepsilon_c-1}\frac{\varepsilon_c-1}{\pi_t} + \lambda_{9t}\omega_c(\hat{P}_{c,t-1}\pi/\pi_t)^{1-\varepsilon_c}(1-\varepsilon_c)\frac{1}{\pi_t}$$

$$-\lambda_{10t}\hat{P}_{c,t}/\hat{P}_{c,t-1} - \frac{1}{\beta}\lambda_{11t-1}\omega_d\beta P1_{dt}(\frac{\pi_t}{\pi})^{\varepsilon_d}\frac{\varepsilon_d}{\pi_t} - \frac{1}{\beta}\lambda_{12t-1}\omega_d\beta P2_{dt}(\frac{\pi_t}{\pi})^{\varepsilon_d-1}\frac{\varepsilon_d-1}{\pi_t}$$

$$+\lambda_{14t}\omega_d(\hat{P}_{d,t-1}\pi/\pi_t)^{1-\varepsilon_d}(1-\varepsilon_d)\frac{1}{\pi_t} - \lambda_{15t}\hat{P}_{d,t}/\hat{P}_{d,t-1} = 0$$

$$\pi_{ct}: \quad \frac{1}{\beta}\lambda_{5,t-1}\beta R_{t-1}\frac{\lambda_t}{\lambda_{t-1}\pi^2_{ct}} + \lambda_{10t} - \lambda_{17t}\omega_c(\frac{\pi}{\pi_{c,t}})^{-\varepsilon_c}\left(\frac{\varepsilon_c}{\pi_{c,t}}\right)s_{c,t-1} - \lambda_{26t-1}(\lambda_t+\gamma_t)/\pi^2_{c,t} = 0$$

$$\pi_{dt}: \quad \lambda_{15t} - \lambda_{18t}\omega_d(\frac{\pi}{\pi_{d,t}})^{-\varepsilon_d}\left(\frac{\varepsilon_d}{\pi_{d,t}}\right)s_{d,t-1} = 0$$

$$\hat{P}^*_{ct}: \quad \lambda_{8t} + \lambda_{9t}(\omega_c-1)\hat{P}^{*-\varepsilon_c}_{ct}(1-\varepsilon_c) + \lambda_{17t}\varepsilon_c(1-\omega_c)\left(\frac{\hat{P}^*_{ct}}{\hat{P}_{ct}}\right)^{-\varepsilon_c-1}\left(\frac{1}{\hat{P}_{ct}}\right) = 0$$

$$\hat{P}^*_{dt}: \quad \lambda_{13t} + \lambda_{14t}(\omega_d-1)P^{*-\varepsilon_d}_{dt}(1-\varepsilon_d) + \lambda_{18t}\varepsilon_d(1-\omega_d)\left(\frac{\hat{P}^*_{dt}}{\hat{P}_{dt}}\right)^{-\varepsilon_d-1}\left(\frac{1}{\hat{P}_{dt}}\right) = 0$$

$$q_t: \quad -\lambda_{4t}\lambda_t + \frac{1}{\beta}\lambda_{4t-1}\beta(1-\delta)\lambda_t + \lambda_{25t} = 0$$

$$R_t: \quad -\lambda_{5t}\beta\frac{\lambda_{t+1}}{\lambda_t\pi_{ct+1}} = 0$$

$$s_{c,t}: \quad \lambda_{17t} - \beta\lambda_{17t+1}\omega_c(\frac{\pi}{\pi_{c,t+1}})^{-\varepsilon_c} + \lambda_{21t}C_t = 0$$

$$s_{d,t}: \quad \lambda_{18t} - \beta\lambda_{18t+1}\omega_d(\frac{\pi}{\pi_{d,t+1}})^{-\varepsilon_d} + \lambda_{22t}(D_t-(1-\delta)D_{t-1}) = 0$$

$$\hat{W}_t: \quad -\lambda_{1t}\lambda_t - \frac{\lambda_{19t}}{A_{ct}} - \frac{\lambda_{20t}}{A_{dt}q_t} = 0$$

$$X_t: \quad X_t^{-1} + \lambda_{2t} + \lambda_{3t}\frac{1-\eta}{\eta}X_t^{\frac{1-2\eta}{\eta}}(1-\alpha)^{\frac{1}{\eta}}C_t^{-\frac{1}{\eta}} + \lambda_{4t}\frac{1-\eta}{\eta}X_t^{\frac{1-2\eta}{\eta}}\alpha^{\frac{1}{\eta}}D_t^{-\frac{1}{\eta}} = 0$$

D Subperiod Estimates

Table 6: Maximum Likelihood Estimation and Standard Error (in parentheses) for Various Subperiods

Parameter	Description	1954Q3-1983Q4	1984Q1-2009Q4	1963Q1-1983Q4
δ	depreciation rate	0.0704	0.0855	0.0688
		0.0053	0.0058	0.0054
η	elasticity of substitution between nondurables and durables	0.1928	0.1401	0.2022
		(0.0183)	(0.0175)	(0.0250)
ω_c	nominal rigidity in nondurable sector	0.8238	0.8371	0.7803
		(0.0126)	(0.0127)	(0.0192)
ω_d	nominal rigidity in durable sector	0.7828	0.7899	0.4953
		(0.0380)	(0.0281)	(0.0613)
ρ_y	policy reaction to output	0.3103	0.3415	0.3013
		(0.0533)	(0.0598)	(0.0544)
ρ_π	policy reaction to inflation	2.5897	2.6650	2.3440
		(0.3113)	(0.3116)	(0.2955)
ρ_c	persistence of technology shock in nondurable sector	0.9171	0.8372	0.9900
		(0.0331)	(0.0329)	(0.0133)
ρ_d	persistence of technology shock in durable sector	0.4487	0.4367	0.8296
		(0.0577)	(0.0361)	(0.0392)
p	periods between signal and realization of productivity	4	4	4
$\sigma_{\xi c}$	standard deviation of nondurable sector news shock	0.0382	0.0342	0.0428
		(0.0035)	(0.0032)	(0.0047)
$\sigma_{\zeta c}$	standard deviation of nondurable sector technology shock	0.0354	0.0343	0.0324
		(0.0039)	(0.0036)	(0.0035)
$\sigma_{\xi d}$	standard deviation of durable sector news shock	0.0218	0.0142	0.0147
		(0.0031)	(0.0015)	(0.0015)
$\sigma_{\zeta d}$	standard deviation of durable sector technology shock	0.0815	0.0656	0.0346
		(0.0167)	(0.0095)	(0.0033)
σ_e	standard deviation of monetary shock	0.0089	0.0053	0.0085
		(0.0015)	(0.0009)	(0.0015)
	log-likelihood	-1754.83	-1734.15	-1212.07

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