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Stéphane Auray
CREST-Ensai, Université du Littoral Côte d'Opale (EQUIPPE), GREDI and CIRPEE

Paul Gomme
Concordia University and CIREQ

Shen Guo
School of Public Finance and Public Policy, Central University of Finance and Economics, Beijing, China

UNIVERSITÉ Concordia UNIVERSITY

Department of Economics, 1455 De Maisonneuve Blvd. West, Montreal, Quebec, Canada H3G 1M8
Tel 514–848–2424 # 3900 · Fax 514–848–4536 · econ@alcor.concordia.ca · alcor.concordia.ca/~econ/repec

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Stéphane Auray
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Shen Guo
School of Public Finance and Public Policy,
Central University of Finance and Economics, Beijing, China.

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Abstract

Capturing the boom phase of Pigou cycles and resolving the comovement problem requires positive sectoral comovement. This paper addresses these observations using a two sector New Keynesian model. Price rigidities dampen movements in the relative price of durables following a monetary policy shock. Durables and nondurables are estimated to be complements in utility, allowing for a resolution of the comovement problem for modest degrees of price rigidity. Nominal rigidities also make firms forward-looking in their pricing behaviour which leads to relative price dynamics that generate positive sectoral comovement in the boom phase of a Pigou cycle.

Two outstanding issues in the literature are addressed in this paper. The first relates to Pigou cycles, defined in the spirit of Beaudry and Portier (2004) as a theory of business cycle booms and recessions in which agents receive imperfect signals of future productivity. As in Christiano *et al.* (2008), we operationalize this definition by considering two classes of shocks: *news shocks* which represent noisy signals of future productivity, and *contemporaneous shocks*, representing changes in current productivity.[1] As emphasised by Beaudry and Portier, a positive news shock

*We are grateful to David Fuller, the editor, Wouter den Haan, and two referees for insightful comments that lead to a substantial revision of the paper. The paper also received valuables comments from the participants at various seminars and conferences.

[1]In particular, news shocks are *not* sunspots which represent extrinsic uncertainty.

should generate an overall business cycle boom in economic activity prior to the realisation of that shock; in a multiple sector model, this means a boom in all sectors.[2] The second outstanding issue pertains to the *comovement problem* as first identified by Barsky *et al.* (2007). More specifically, the empirical evidence indicates that following a tightening in monetary policy, output of durables and nondurables falls; see Erceg and Levin (2006). According to Barsky *et al.*, many macroeconomic models have difficulty generating this dynamic. The problem is that in response to a monetary contraction, the price of durables relative to that of nondurables falls enough to lead households to *increase* their purchases of durables; hence the comovement problem whereby durables and nondurables move in opposite directions.

The model includes a number of key components. News shocks are needed to be able to consider Pigou cycles. The model is New Keynesian with sticky prices and money-in-the-utility function, widely accepted model of monetary policy. The production side is characterised by two sectors, durables and nondurables, allowing us to address the comovement problem. Each sector is populated by monopolistically competitive intermediate goods producers whose goods serve as inputs to a sector-specific final good. Following the New Keynesian literature, intermediate goods firms periodically reoptimize their prices as in Calvo (1983). In brief, the model has the minimal set of features required to produce Pigou cycles as well as to address the comovement problem.

Model parameters are identified by a combination of calibration and estimation using Bayesian methods. According to Leeper *et al.* (2011), there are important econometric problems in identifying anticipated (news) shocks using astructural methods. Estimating a structural model, as do Schmitt-Grohé and Uribe (ming), imposes sufficient structure to enable the identification of several anticipated shocks.[3] Three features of the parameterization are important at this stage. First, the sectoral price rigidity parameters are calibrated in line with microeconomic evidence on average price durations presented in Klenow and Malin (2011). Second, the elasticity of substitution between durables and nondurables is estimated and found to be much less than unity. Third, the

[2]While Beaudry and Portier (2004) emphasise both booms and busts, here we focus on the boom phase of the Pigou cycle in response to a positive news shock. The bust phase of the cycle arises in Beaudry and Portier when the positive news shock is offset by a negative contemporaneous shock. Our model would deliver such a dynamic; the response to a negative contemporaneous shock is simply the mirror image of the response to a positive contemporaneous shock.

[3]Khan and Tsoukalas (2011) and Gortz and Tsoukalas (2011) also structurally estimate models with news shocks.

stochastic processes of the model – monetary policy as well as sectoral news and contemporaneous shocks – are also estimated. In the aforementioned parameterization, considerable discipline is placed on the results generated.

The benchmark model generates the boom phase of Pigou cycles – a rise in durable and nondurable sector outputs upon receipt of the news – in response to a nondurable sector news shock (but not to a durable sector news shock).[4] The nondurable news shock makes households feel wealthier; as a result, they want to consume more durables, nondurables and leisure. However, to enjoy more leisure, households must work less, which is inconsistent with producing more durable and nondurable output. Consequently, the real wage must rise in order to get households to supply more labour. The increase in the real wage implies higher marginal costs to firms. Owing to nominal rigidities, firms are forward-looking in their pricing behaviour and set prices based on current and future marginal costs. The news shock means that nondurable sector marginal costs will be lower in the future, leading nondurable sector firms to start lowering prices before the shock is realised; this effect is absent in a flexible price model. For the nondurable sector, the effect of the news shock on future marginal costs outweighs the consequences of the higher real wages, and nondurable prices start falling upon receipt of the news shock. Key to the dynamics of durable sector output is the behaviour of the price of durables relative to that of nondurables. The evolution of this relative price is governed by the interplay of the decision of firms and households. In light of the higher marginal costs associated with higher real wages, the relative price of durables must increase in order for firms to be willing to supply that output. Furthermore, to get a boom in the durable sector requires a rising relative price of durables to encourage households to purchase durables before their price rises too much. However, if this hike in the relative price is too high or too rapid, households will delay their purchases of durables leading to a durable sector bust.

Several factors play an important role in our Pigou cycle results. First, the elasticity of substitution between durables and nondurables is estimated to be 0.2563 which means that these goods are complements in utility. As a result, households are reluctant to substitute the consumption of nondurables for durables. Instead, they tend to prefer to increase consumption of both goods at

[4] In addition to the papers already mentioned, other noteworthy papers from the Pigou cycle literature include: Beaudry and Portier (2007), Jaimovich and Rebelo (2009), den Haan and Kaltenbrunner (2009), den Haan and Lozej (2011).

the same time. If, instead, durables and nondurables are sufficiently substitutable in utility, Pigou cycles do not arise following a nondurable sector news shock because households are willing to consume more nondurables, reducing their purchases of durables and so letting its stock decline.

Second, sticky prices are important because they induce forward-looking behaviour on the part of firms, leading to movements in the relative price of durables in advance of the realisation of the news shock. Results are also presented for lower durable sector nominal rigidities relative to the benchmark model. In these cases, there is a bust in the durable sector in the periods leading up to the realisation of the news shock; the relative price of durables rises too much and too fast, leading households to postpone their durables purchases.

Finally, monetary policy plays a role in generating Pigou cycles.[5] In particular, Pigou cycles do not arise if the interest rate rule responds sufficiently strongly to inflation, or sufficiently weakly to output. In these cases, the relative price of durables moves very little for a few periods following receipt of the news shock, then rises sharply. In response, households first build up their stock of durables (while the price is low), lowering their purchases of nondurables. Later, when the relative price has risen, they ease off on their purchases of durables and start increasing their nondurables purchases.

The benchmark model also provides a partial resolution of the comovement problem in the sense that, on impact, a tightening of monetary policy leads to a decline in both durable and nondurable sector outputs (but not in subsequent periods). As previously discussed, many macroeconomic models (especially those with flexible prices) fail to generate this dynamic as the relative price of durables falls sufficiently to generate a boom in durable sector output. As in Barsky *et al.* (2007) and Sterk (2010), sticky prices are an element of the solution.[6] In brief, sticky prices serve to moderate the decline in the relative price of durables sufficiently that durables output drops.

An important contribution of our paper is that for our estimated elasticity of substitution between durables and nondurables, we need less durable sector price stickiness to obtain positive comovement. In particular, durables and nondurables are estimated to be complements in utility

[5]Other notable papers addressing the role of monetary policy in generating Pigou cycles include Kobayashi and Nutahara (2010) and Christiano *et al.* (2008).

[6]Carlstrom and Fuerst (2006) find that wage rigidity along with firm-level adjustment costs on the level of production can resolve the comovement problem in a two sector New Keynesian model.

which implies that households are fairly averse to substitute durables for nondurables. When the elasticity of substitution between durables and nondurables is higher, durable sector prices must be stickier in order to avoid the comovement problem. For the estimated elasticity of substitution between durables and nondurables (0.2563), durable prices do not need to be very sticky to resolve the comovement problem: an average duration of 1.1 quarters does the trick. In the literature, it is common to focus on the case in which this elasticity is one, meaning that durables and nondurables aggregate via a Cobb-Douglas function; in this case, the average duration of durables prices must be at least 1 1/4 quarters to resolve the comovement problem.

Our benchmark setting for nominal price rigidities is based on evidence from Klenow and Malin (2011) for regular price changes; for the durable sector, their results imply an average duration of durable sector prices of 1 2/3 quarters, well within the region that resolves the comovement problem for both our estimated elasticity of substitution and for the Cobb-Douglas case. Alternatively, consider the empirical evidence in Bils and Klenow (2004) which implies that the average duration of durable prices is 1.11 quarters. For this setting of the durable sector price rigidity, an elasticity of one between durables and nondurables does not resolve the comovement problem while it is resolved for our estimated elasticity. There is no compelling reason to think that this elasticity should equal one, and values different from one cannot be ruled out by, say, balanced growth considerations.

The model is presented in Section 1; it is estimated in Section 2. The principle results of the paper are contained in Section 3 which presents impulse responses to various shocks. Section 4 contains some concluding remarks.

1. 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 uses labour 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.

Households supply labour and buy final goods. A central bank conducts monetary policy.

1.1. Households

The representative household has preferences over state-contingent streams of nondurables, C_t, durables, D_t, labour, N_t, and real money balances, M_t/P_t, summarised by

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

The functional form of U is

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

where $\eta > 0$ is the elasticity of substitution between durables and nondurables, α governs the importance of durables relative to nondurables, υ determines the disutility of labour, $1/\sigma$ is the Frisch labour supply elasticity, and χ gives the importance of real money balances.

The household hires out its time, N_t, at nominal wage W_t. In addition to money balances, the household 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, 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,

$$P_{ct}C_t + P_{dt}\left[D_t - (1-\delta)D_{t-1}\right] + B_t + M_t = W_t N_t + R_{t-1}B_{t-1} + M_{t-1} + T_t + \Pi_{ct} + \Pi_{dt}, \tag{3}$$

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 chooses contingent sequences, $\{C_t, D_t, N_t, B_t, M_t\}_{t=0}^{\infty}$, to maximise Eq. (1) subject to Eq. (3) given B_{-1} and M_{-1}.

1.2. 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

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

where $\epsilon_j > 0$ is the elasticity of substitution between the differentiated goods in sector j. The final goods firms' cost minimisation problem leads to the demand function for intermediate good i,

$$Y_{jt}(i) = \left(\frac{P_{jt}(i)}{P_{jt}}\right)^{-\epsilon_j} Y_{jt}, \tag{4}$$

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

1.3. 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. (4) and has access to a technology that only uses labour:

$$Y_{jt}(i) = A_{jt} N_{jt}(i), \tag{5}$$

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

As in much of the New Keynesian 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 maximise the following expression for expected discounted profits:

$$E_t \sum_{k=0}^{\infty} \omega_j^k \Delta_{t,t+k} \left[\frac{(1+\tau_j)\pi^k P^*_{jt}}{P_{c,t+k}} Y_{j,t+k} - MC_{j,t+k} Y_{j,t+k}\right], \tag{6}$$

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), $\Delta_{t,t+k} = \beta^k U_c\left(C_{t+k}, D_{t+k}, N_{t+k}, \frac{M_{t+k}}{P_{t+k}}\right) / U_c\left(C_t, D_t, N_t, \frac{M_t}{P_t}\right)$, meaning that the firm discounts real profits (measured in units of the nondurable good) according to the marginal rate of substitution for nondurable goods over time. Firm profits are given by the term in square brackets in Eq. (6),

In Eq. (6), τ_j is a fixed subsidy rate. As in Rotemberg and Woodford (1997), setting $\tau_j =$

$1/(\epsilon_j - 1)$ 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. (6) yields

$$P_{jt}^* = \frac{1}{1+\tau_j}\frac{\epsilon_j}{\epsilon_j - 1}\frac{E_t \sum_{k=0}^{\infty} \omega_j^k \beta^k \pi^{-\epsilon_j k} U_c\left(C_{t+k}, D_{t+k}, N_{t+k}, \frac{M_{t+k}}{P_{t+k}}\right) MC_{j,t+k} Y_{j,t+k} P_{j,t+k}^{\epsilon_j - 1} P_{c,t+k}}{E_t \sum_{k=0}^{\infty} \omega_j^k \beta^k \pi^{(1-\epsilon_j)k} U_c\left(C_{t+k}, D_{t+k}, N_{t+k}, \frac{M_{t+k}}{P_{t+k}}\right) Y_{j,t+k} P_{j,t+k}^{\epsilon_j - 1}}. \quad (7)$$

In terms of understanding the results in this paper, the key observation from Eq. (7) is that firms' pricing behaviour is forward looking. Specifically, a news shock contains information concerning the future marginal cost, and so will affect firms' pricing before the realisation of that shock.

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

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

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

$$P_t = (P_{ct}Y_{ct} + P_{dt}Y_{dt})/(Y_{ct} + Y_{dt}),$$

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

1.4. Productivity

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

$$\ln A_{jt} = \rho_j \ln A_{j,t-1} + \xi_{j,t-p} + \zeta_{jt}, \quad |\rho_j| < 1, \quad (8)$$

where $\xi_{j,t-p} \sim N(0, \sigma_{\xi j}^2)$ is the *news shock* received p periods ago, while $\zeta_{jt} \sim N(0, \sigma_{\zeta j}^2)$ is a conventional, *contemporary productivity shock*. Given the setup in Eq. (8), a news shock is a noisy signal of the future state of technology in a sector.

1.5. *Monetary Policy*

The central bank follows a Taylor (1993)-style interest rate rule:

$$\ln R_t = \ln R^* + \rho_\pi(\ln \pi_t - \ln \pi) + \rho_y(\ln Y_t - \ln Y) + e_t, \tag{9}$$

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

1.6. *Aggregation and Equilibrium*

Aggregation follows familiar steps from the New Keynesian literature. Integrating both sides of the intermediate goods production technology, Eq. (5), gives

$$\int_0^1 Y_{jt}(i) = \int_0^1 A_{jt} N_{jt}(i) di = A_{jt} N_{jt}, \tag{10}$$

where $N_{jt} = \int_0^1 N_{jt}(i)di$. Substituting for $Y_{jt}(i)$ in Eq. (10) using the demand function, Eq. (4), delivers

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

where s_{jt} captures the inefficiencies associated with price dispersion arising from the Calvo (1983)-style staggered price reoptimization.

The definition of a (recursive) equilibrium is fairly standard and is omitted for the sake of brevity. The equations characterising equilibrium, including transformations to render nominal magnitudes stationary, are collected in an on-line appendix.

2. Estimation

As An and Schorfheide (2007) suggest, estimates of structural parameters generated with straight maximum likelihood procedures based on a set of observations are often at odds with the results obtained in previous micro-econometric or macro-econometric studies. The use of Bayesian techniques incorporates this prior information and this is the approach employed below. Given the estimated parameter values, 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, as well as provide a solution to the comovement problem associated with monetary policy.

Some parameters are difficult to estimate because they have little effect on the likelihood; see Smets and Wouters (2003) and Ireland (2001), among others. These parameters are set based on *a priori* information and are summarised in Table 1. For the most part, the calibration targets are standard and/or self-explanatory.[7]

The parameters governing price rigidity, ω_c and ω_d, are set in line with microevidence presented in Klenow and Malin (2011). Specifically, they report mean durations of regular prices (that is, excluding sales) of 5.0 months for durables, and 8.3 months for nondurables.[8] Given that a model period is three months, these average price durations correspond to $\omega_d = 0.4$ and $\omega_c = 0.64$, remembering that these are the probabilities of *not* reoptimizing prices.

The remaining parameters are estimated via Bayesian techniques as in Schorfheide (2000), Smets and Wouters (2003, 2007), Lubik and Schorfheide (2004, 2006), and Rabanal and Rubio-Ramirez (2005). The five variables appearing in the observation equation are: average labour productivity in the nondurable goods sector, A_{ct};[9] average labour productivity in the durable goods sector, A_{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 1964Q1–2011Q2. Sectoral productivities are measured by sectoral output per hour worked, where durable sector output is measured by real per capita durable goods consumption, and nondurable sector output is measured by real per capita nondurable consumption plus services; aggregate output is measured by real per capita GDP; the nominal interest rate is measured by the federal funds rate. The data are described in more detail in the on-line appendix.

The third to fifth columns in Table 2 report the assumptions regarding the prior distribution of the parameters to be estimated. The on-line appendix plots the prior and posterior distributions

[7]See the on-line appendix for more details concerning the calibrated parameters.

[8]The duration for services prices is even longer, 9.4 months. Given that our results depend on having price rigidity, combining services with nondurables would lead to greater price rigidity in the nondurable sector, and so would serve to strengthen the effects in our paper.

[9]Given that output is linear in labour, average labour productivity coincides with total factor productivity.

Table 1: Calibrated parameters

Parameter	Value	Target	Value
β	0.99	Annual real interest rate	4%
δ	0.058	Quarterly depreciation rate	5.8%
α	0.77	Durables share of output	0.25
σ	1	Frisch labour supply elasticity	1
υ	0.94	Steady state labour	1
μ	2.56	Interest elasticity of money demand	0.39
χ	0.0001	Steady state money to output ratio	0.129
ϵ_c, ϵ_d	6	Steady state markup	20%
π	1.01	Annual steady state inflation rate	4%
ω_d	0.4	Microevidence	
ω_c	0.64	Microevidence	

of the parameters. Of the estimated parameters, a few deserve mention given their importance in our results. The prior over the elasticity of substitution between durables and nondurables is a gamma distribution with mean 0.2 – the same value as estimated by Beaudry and Portier (2004) – and standard deviation 0.05. Gamma distributions are chosen for the priors over the shocks since, as Schmitt-Grohé and Uribe (ming) point out, the gamma distribution allows for positive density at zero, and thus allows for the possibility that some of the shocks simply do not matter. For the standard deviations of the technology shocks, the means are set to 0.05 and the standard deviations to 0.025. The mean for the standard deviation of the monetary policy shock is smaller, 0.01.

Finally, we come to the correlations among the innovations to the shocks. Theory predicts that the monetary policy shocks should be uncorrelated with the other shocks, so this restriction is imposed.[10] Of the remaining six correlations, theory also predicts that only those between the two news shocks, and between the contemporaneous shocks should be non-zero; these restrictions are imposed.[11] The priors over the non-zero shock correlations are normally distributed with means of zero and standard deviations of 0.3.

[10] Unconstrained estimation reveals that these correlations are close to zero; see the on-line appendix.

[11] In the on-line appendix, additional shock correlations are estimated. Of these, only that between the nondurable news and nondurable contemporaneous shock is significantly different from zero, suggesting that what we have identified as 'news shocks' may not represent purely expectational effects of future productivity. Fortunately, the remaining parameter estimates are not very sensitive to imposing zero correlations between the various news and contemporaneous shocks. Further, a consequence of log linearizing the model (which is necessary for estimating the model) is that these correlations do not enter into the model's solutions.

Table 2 reports the means and 90% confidence intervals of the posterior distributions of the model's parameters (see columns six through eight). The posterior for the elasticity of substitution between durables and nondurables, η, is 0.2563 which means that durables and nondurables are complements in utility. This value is slightly larger than that estimated by Beaudry and Portier (2004), 0.2; an implication is that the estimated value allows somewhat more substitution between durables and nondurables than Beaudry and Portier.

In the nondurable sector, news and contemporaneous shocks are roughly as volatile; in the durable sector, the contemporaneous shocks are more variable. Further, the durable sector shocks have higher standard deviations than the nondurable sector shocks.

Turn next to the correlations between the shocks. The priors over these correlations are quite dispersed, allowing the data to speak more forcefully. The estimated correlations – between the two news shocks and between the two contemporaneous shocks – are large and negative. These correlations are inconsistent with a two sector interpretation of the one sector growth model which implies that the two contemporaneous shocks, for example, have a correlation of one.

There is a final parameter to comment upon: p, the number of periods in advance that a news shock is revealed. The model is estimated for a range of values for p; Table 2 corresponds to $p = 7$ which maximises the (log) data density.

The on-line appendix provides a number of alternative estimations. Broadly speaking, these alternatives can be grouped as follows: (1) alternative settings for the price rigidity parameters; (2) alternative priors over various model parameters; and (3) various zero restrictions on the correlations among the model shocks. For the most part, the estimates are not very sensitive to these changes; apart from flexible durables prices, neither are the results of the impulse responses.

3. Impulse Responses

This section presents impulse responses to the model's shocks. In order to concentrate exclusively on the effects of a particular shock, the correlations between the shocks are set to zero so that an impulse to one shock does not spill over to any of the other shocks. Simulations of the model with correlated shocks gives qualitatively similar results, but are harder to interpret.

Table 2: Benchmark estimation results

Parameter	Description	Prior distribution			Posterior distribution		
		Type	Mean	Std. Dev.	Mean	90% interval	
η	elasticity of substitution between nondurables and durables	gamma	0.2	0.025	0.2563	0.2181	0.3007
ρ_y	policy reaction to output	gamma	0.5	0.025	0.3839	0.3577	0.4079
ρ_π	policy reaction to inflation	gamma	1.5	0.05	1.4056	1.3699	1.4422
ρ_c	persistence of shocks in nondurable sector	beta	0.7	0.05	0.9248	0.9159	0.9327
ρ_d	persistence of shocks in durable sector	beta	0.7	0.05	0.9289	0.9225	0.9327
Standard deviations:							
$\sigma_{\xi c}$	nondurable sector news	gamma	0.05	0.025	0.0246	0.0220	0.0272
$\sigma_{\zeta c}$	nondurable sector contemporaneous	gamma	0.05	0.025	0.0227	0.0208	0.0247
$\sigma_{\xi d}$	durable sector news	gamma	0.05	0.025	0.0344	0.0318	0.0375
$\sigma_{\zeta d}$	durable sector contemporaneous	gamma	0.05	0.025	0.0423	0.0399	0.0462
σ_e	monetary	gamma	0.01	0.005	0.0160	0.0146	0.0172
Shock correlations:							
$\sigma_{\xi c \xi d}$	nondurable news, durable news	normal	0.0	0.3	−0.5811	−0.6501	−0.4932
$\sigma_{\zeta c \zeta c}$	nondurable contemporaneous, durable contemporaneous	normal	0.0	0.3	−0.5792	−0.6559	−0.5127
log data density: −2329.19							

3.1. Pigou Cycles

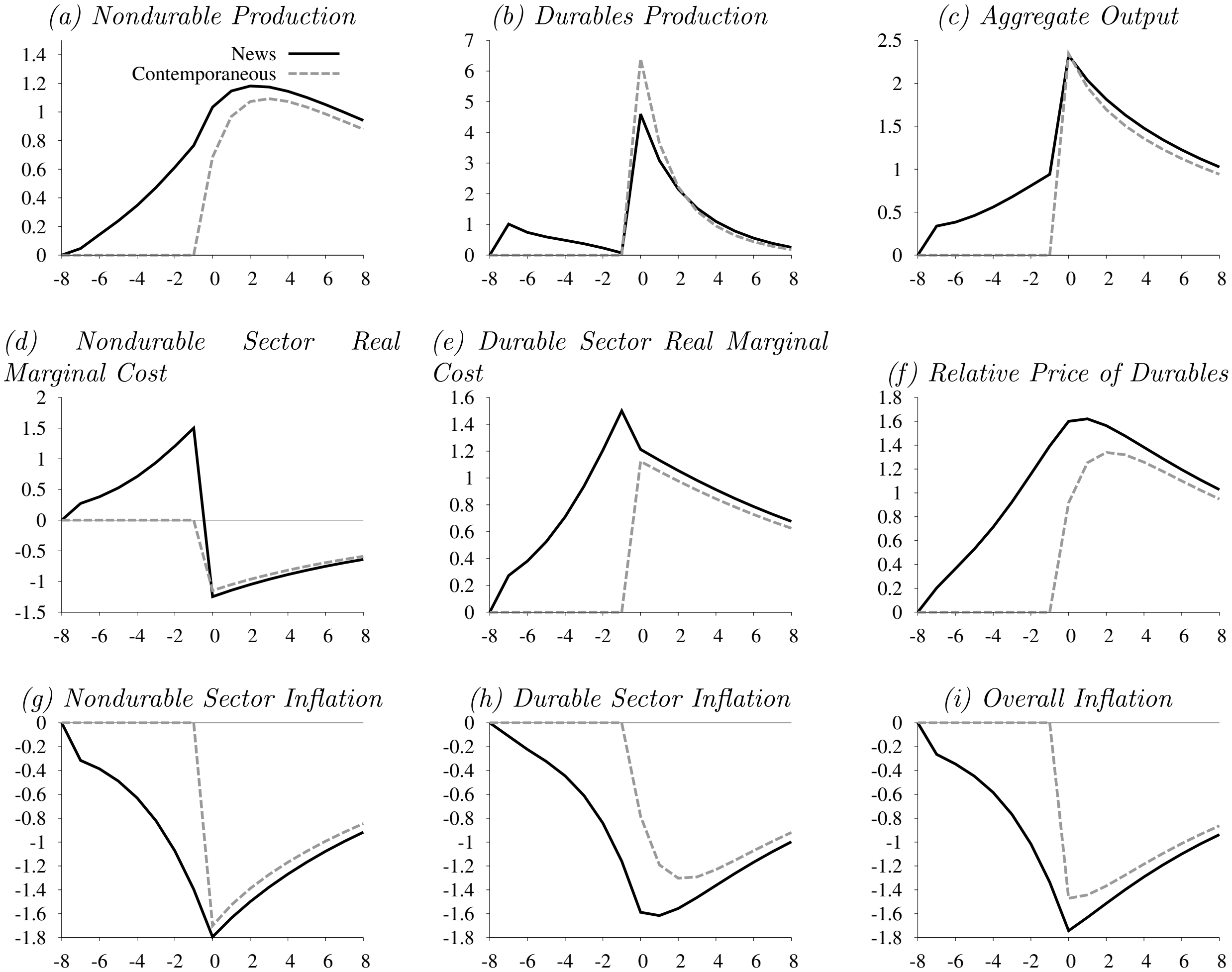
Figure 1 presents impulse responses for: (a) a nondurable sector news shock received at time $t = -7$, coming into effect at $t = 0$; and (b) a nondurable sector contemporaneous shock received at $t = 0$. Both shocks are positive one standard deviation events, and the responses are expressed as percentage deviations from steady state. The first item to note is that from time $t = 0$ forward, the effects for the two shocks are qualitatively similar, in particular for aggregate output and overall inflation. However, under a news shock, variables move in advance of the realisation of the shock at $t = 0$. Of particular interest is the fact that a nondurable sector news shock leads to a business cycle boom, manifested in both sectors, and thus in employment and aggregate output. Observing a positive response of macroeconomic variables to a news shock is an important component of the Pigou cycle literature.

The dynamics following a news shock are determined by three factors. First, the news shock makes households feel wealthier and so, all else equal, they would like to consume more nondurables, durables and leisure, the last of which implies lower labour. However, to accommodate increased output requires *more* labour which means that the real wage must increase to entice households to provide that labour. This increase in the real wage necessarily increases firms' marginal costs; see Figures 1d and 1e.

Second, the news shock implies that, in the future, the marginal cost of producing nondurables will be lower; see Figure 1d. 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 realisation as can be inferred from the path of nondurable sector inflation in Figure 1g.

Third, the dynamics of durables depends on the behaviour of the relative price of durables which is determined by the interplay of the decisions made by both households and firms. Households' purchases of durables also have a forward-looking element owing to their relatively long lives. Holding the relative price of durables fixed, the estimated elasticity of substitution between durables and nondurables implies that these two goods are complements in utility, and so house-

Fig. 1: Responses to nondurable good sector shocks

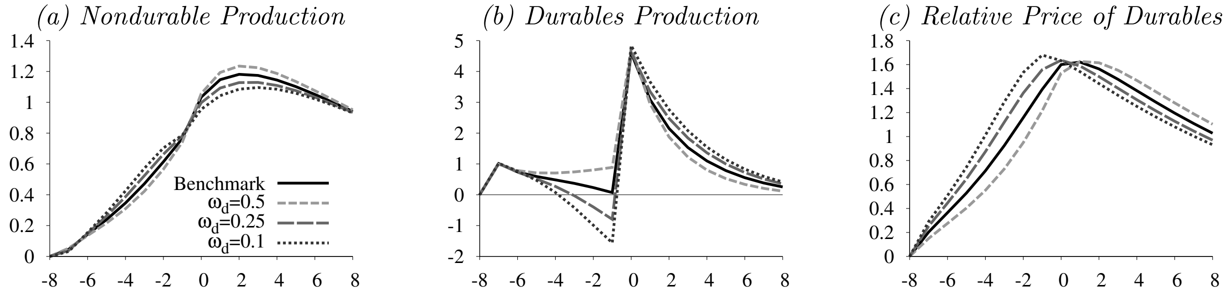


Note: The news shock is received at time $t = -7$, and so is realised at $t = 0$; the contemporaneous shock is received at $t = 0$.

holds prefer to increase (or decrease) their consumption of both goods together. If, as in Figure 1f, the relative price of durables rises quickly, then households will buy up durables *before* their price has risen too much. In this case, the steep rise in the price of durables prior to the realisation of the news shock at $t = 0$ leads to a durable sector boom.

To further explore the role of durable sector price rigidities, Figure 2 presents impulse responses for durables and nondurables production in response to a nondurable sector news shock for different degrees of price rigidities; a complete set of results are available in the on-line appendix. The message from this figure is that as the price of durables becomes less rigid, durables production eventually falls below steady state in the periods just prior to the realisation of the news shock.

Fig. 2: Responses to nondurable good sector news shock: alternative assumptions regarding nominal rigidities

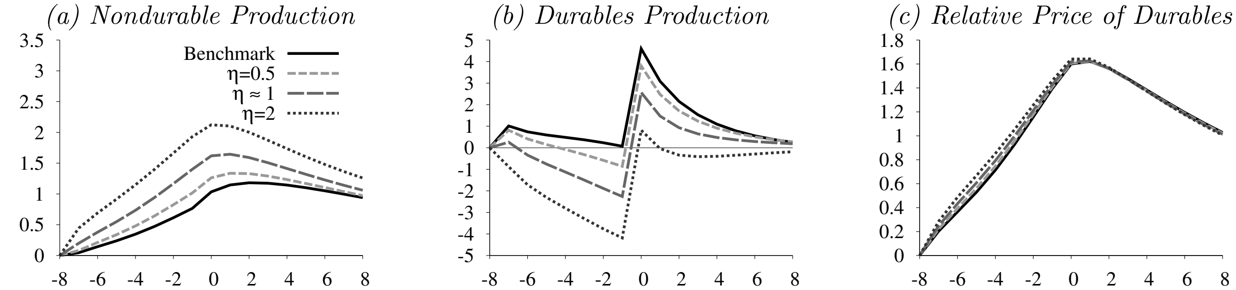


Driving these results is the path of the relative price of durables. When durables prices are not too rigid, the relative price rises rapidly, peaking two periods before the shock takes effect. This strong increase in the relative price leads households to postpone their durables purchases, hence the decline in durables output just prior to the realisation of the shock.

Figure 3 shows that the elasticity of substitution between durables and nondurables is extremely important in generating a general business cycle boom in response to a nondurable sector news shock. For all of the alternatives considered, the nondurable sector news shock generates a boom in the nondurable sector upon receipt of the news shock. The durable sector is another story. Increasing this elasticity to 0.5 leads to a durable sector bust in the 4 quarters before the news shock takes effect. When the elasticity is around 1 (the Cobb-Douglas case), there is a small boom in the durable sector in the period that the news shock is received, followed by a bust until the shock takes effect. Further increasing this elasticity to 2, one sees a bust in the durable goods sector in all of the periods before the news shock is realised. Notice that the trajectory of the relative price of durables is quite similar across the various values for the elasticity of substitution between durables and nondurables. The similarity in this trajectory shows that it is the estimated complementarity between durables and nondurables ($\eta = 0.2563$) that leads to the positive comovement following a news shock. When durables and nondurables are substantially more substitutable in utility than in the benchmark model, there is a durable sector bust following receipt of a nondurable sector new shock. Interestingly, Beaudry and Portier (2004) estimate $\eta = 0.2$.

Figure 4 assesses the role of monetary policy in generating Pigou cycles. Relative to the benchmark model, two alternative scenarios are considered: "stronger inflation," corresponding to

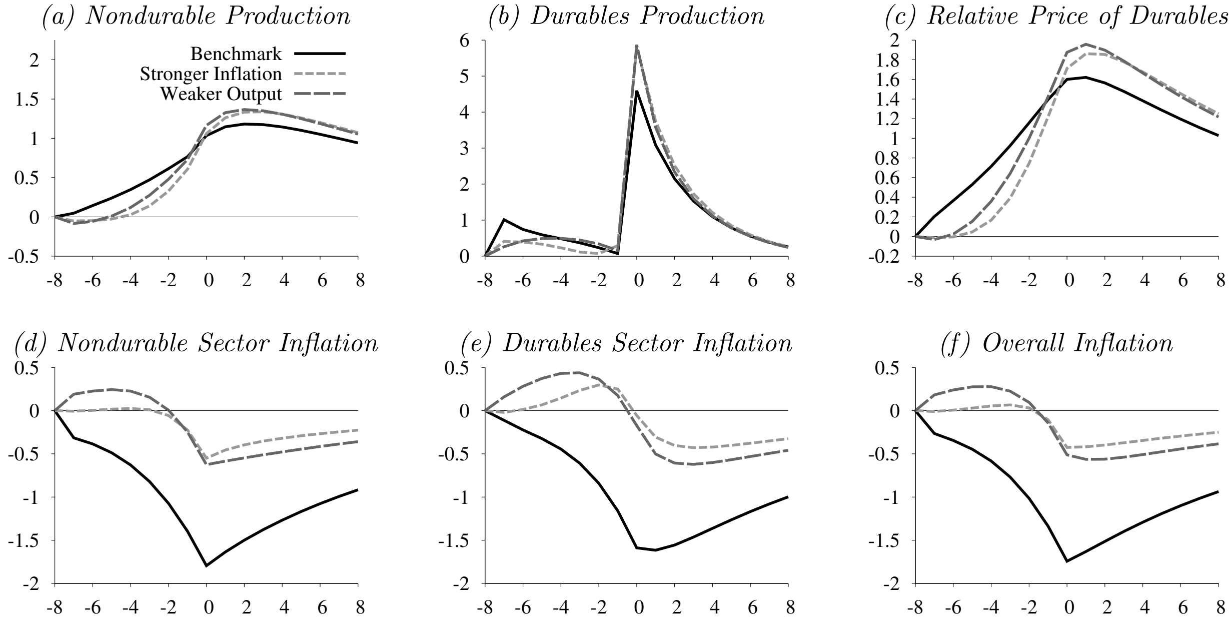
Fig. 3: Responses to a nondurable good sector news shock: alternative assumptions regarding the elasticity of substitution between durables and nondurables



increasing the value of the parameter on inflation in the interest rate rule, ρ_π, to 3; and "weaker output" which reduces the value of the parameter on output, ρ_y, to 0.1. Relative to the benchmark model, these alternative monetary policies dampen not only overall inflation, but sectoral inflation rates as well. As a result, the relative price of durables initially does not move very much, but then rises more rapidly than in the benchmark model. Consequently, households initially increase their purchases of durables to build up its stock before the price rises; this increase in durables purchases is financed in part by reducing purchases of nondurables. Later, when the relative price of durables starts rising quickly, households reduce their purchases of durables and increase that of nondurables. In brief, these alternative settings for monetary policy lead to a moderate nondurable sector bust in the periods immediately following receipt of the nondurable sector news shock. The results summarised in Figure 4 suggest that there is a very real sense in which monetary policy can be said to cause Pigou cycles in our model economy.

The shaded area of Figure 5 gives the combinations of the policy parameters, ρ_y and ρ_π, that lead to Pigou cycles following a nondurable sector news shock. To generate this figure, the model is solved for several combinations of (ρ_y, ρ_π) with all other parameters at their estimated values. The figure shows that the larger the weight on output, the larger the weight on inflation must be to avoid Pigou cycles. For example, when the weight on output is 0.2, Pigou cycles do not occur when the weight on inflation is higher than 1.3. Increasing the weight on output to 0.4 requires a weight on inflation above 1.6 to avoid Pigou cycles. Recall that the estimated parameters are $\rho_y = 0.3839$ and $\rho_\pi = 1.4056$ which are well within the region leading to Pigou cycles. The intuition behind the results summarised in Figure 5 is the same as for Figure 4: a stronger policy reaction to inflation

Fig. 4: Responses to nondurable good sector news shock: the role of monetary policy

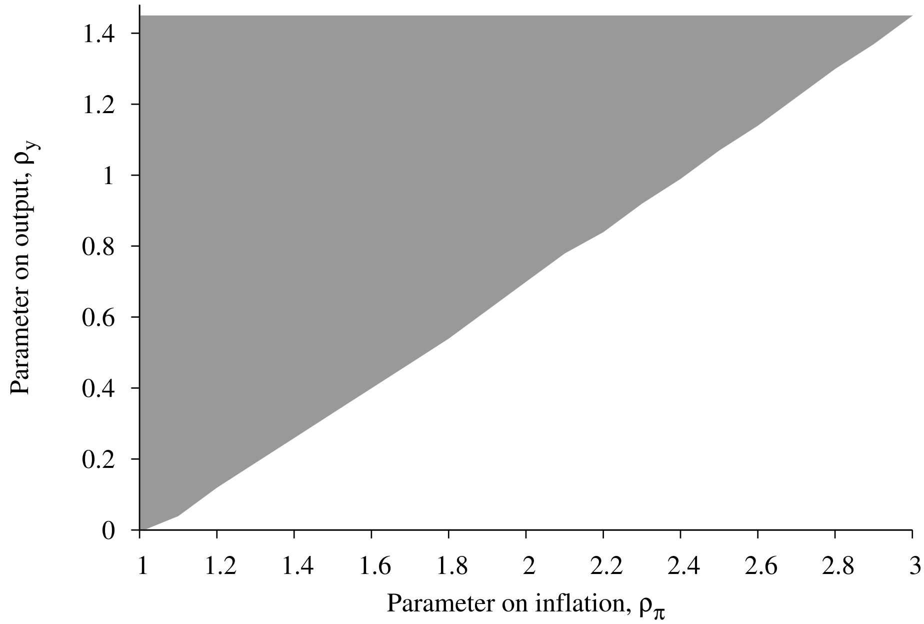


leads to an initially weak response of the relative price of durables (during which households shift the mix of their purchases towards durables), followed by a rapidly rising relative price (at which point households change the mix of purchases towards nondurables). The same is true when the policy reaction to output is weaker.

The effects of a durable sector news shock and contemporaneous shock are presented in Figure 6, with the shock timing as in Figure 1.[12] Concentrating on the effects of the news shock, while the nondurable sector booms immediately, the durable sector does not. In fact, until the realisation of the shock at $t = 0$, durable sector output is below steady state. As with the nondurable news shock, the behaviour of the relative price of durables is key to the response of the durable sector. In this case, the relative price of durables does not rise much upon receipt of the news shock, and actually falls below steady state in the periods just prior to the realisation of the shock. As a consequence, households put off their purchases of durables until their relative price is quite low (around the time that the news shock takes effect), switching their mix of purchases to nondurables. Around time $t = 0$, when the news shock takes effect, households then switch the mix from nondurables to durables. In summary, there is a durable sector bust from receipt of this news shock until it actually takes effect; similar results are obtained in Beaudry and Portier (2004). Thus, in our

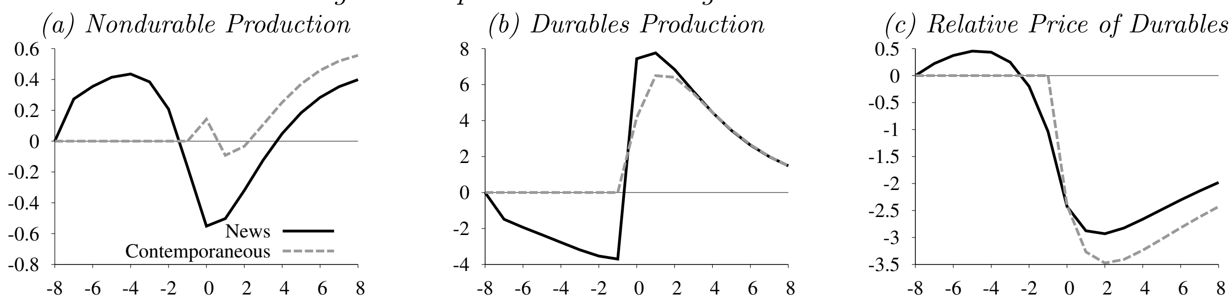
[12] A more comprehensive set of impulse responses are contained in the on-line appendix.

Fig. 5: Policy parameter region that results in Pigou cycles



Note: Pigou cycles occur in the shaded region.

Fig. 6: Responses to durable good sector shocks



model, durable sector news shocks do not lead to Pigou cycles.

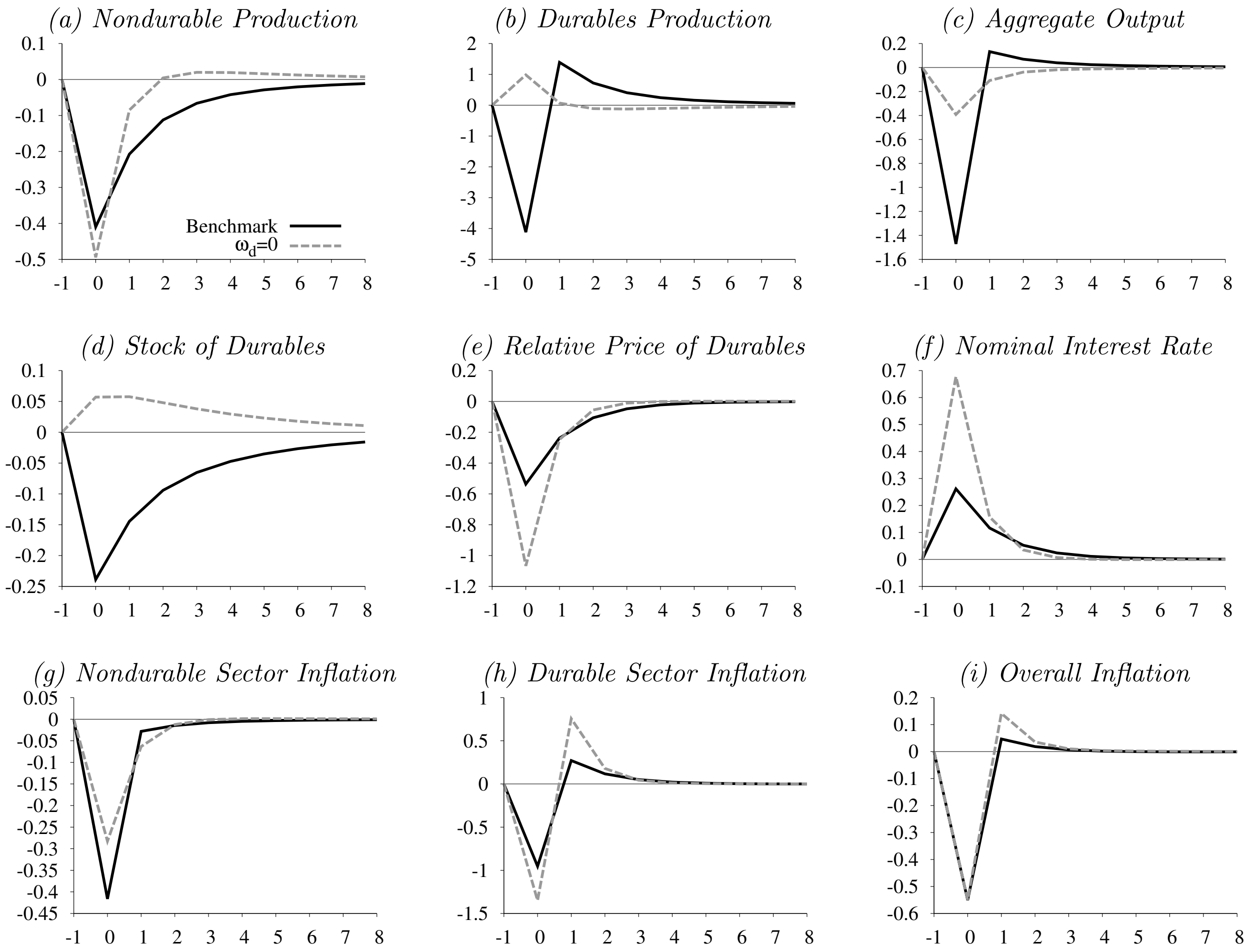
3.2. The Comovement Problem

Finally, the responses to a monetary policy shock can be found in Figure 7. This shock corresponds to a positive innovation to the interest rate rule, Eq. (9) – that is, a tightening of monetary policy. The solid line presents the responses under the estimated parameter values. To understand these results, it is perhaps easiest to first consider what happens when durables prices are perfectly flexible (the dotted line); that is, when ω_d, the non-reoptimization probability, equals zero. Tighter monetary policy reduces inflation in both sectors. When durables prices are flexible, the nominal price of durables falls sharply, as does the relative price of durables. This sharp fall in the relative price of durables encourages consumers to purchase more durables, partly offsetting the effect of tighter monetary policy. At the same time, purchases of nondurables fall. The net result is what has come to be termed the *comovement problem*, whereby a monetary policy shock leads to *opposite* movements in the output of durables and nondurables. The data, on the other hand, point to positive comovement between the two sectors following such a shock; see Erceg and Levin (2006).

Return now to the benchmark model (solid line) for which the durable sector price non-reoptimization probability is 0.4 (an average duration of prices of 1 2/3 quarters). The durable sector nominal rigidities now imply a more modest fall in inflation in that sector. As a result, the fall in the relative price of durables is smaller than when the price of durables is flexible. The fall in the relative price of durables is no longer sufficient to offset the contractionary effects of the monetary policy shock and durables purchases fall on impact, as does that of nondurables. Thus, on impact, the estimated model exhibits positive comovement between durables and nondurables. In subsequent periods, the relative price of durables is rising, and households increase their durables purchases above steady state while that of nondurables remains below its steady state level. In other words, the estimated model presents a partial resolution of the comovement problem in the sense that we get positive comovement on impact, but not in subsequent periods.

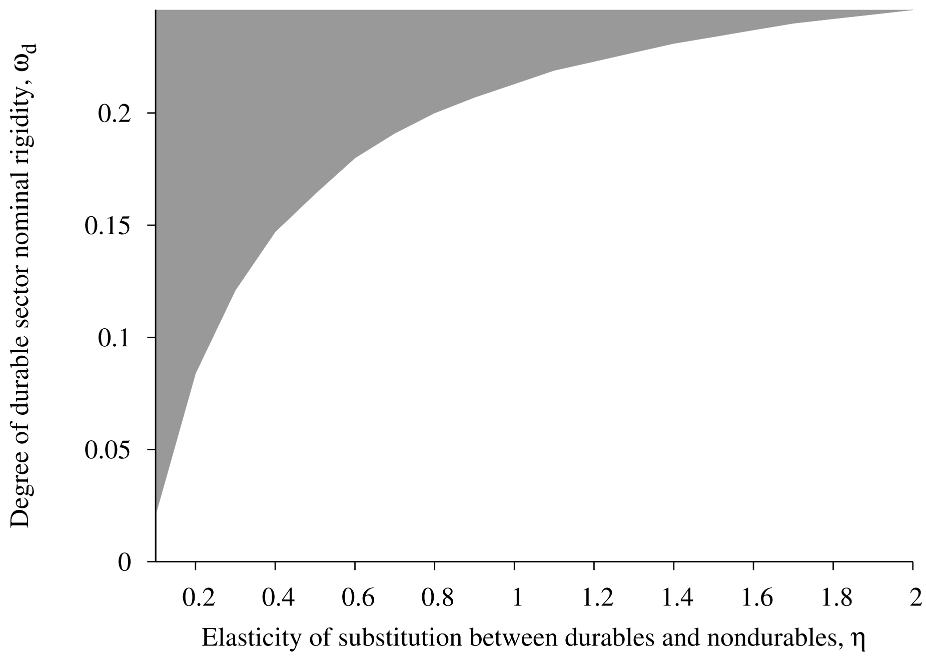
The elasticity of substitution between durables and nondurables, η, is driving this partial resolution of the comovement problem. The estimated value of this parameter, 0.2563, implies that durables and nondurables are complements in utility. In the comovement problem literature, starting with Barsky *et al.* (2007), it is common to set this elasticity to one, that is, a Cobb-Douglas aggregator over durables and nondurables. The shaded region in Figure 8 gives combinations of the elasticity of substitution between durables and nondurables (η), and the degree of durable sector nominal rigidity (ω_d) that provide a resolution of the comovement problem. The message to take away from this figure is that as the elasticity of substitution between durables and nondurables rises, the model needs more durable sector rigidity (higher values of ω_d) in order to resolve the comovement puzzle. For the estimated value of η, only a modest degree of durable sector price

Fig. 7: Responses to a monetary policy shock



Note: The shock is a positive monetary policy shock occurring at time $t = 0$.

Fig. 8: Resolving the comovement problem: the elasticity of substitution between durables and nondurables, and the degree of durable sector nominal rigidity



stickiness is needed. Price rigidity in the benchmark model was calibrated using average price duration reported in Klenow and Malin (2011) and corresponds to $\omega_d = 0.4$. Figure 8 shows that for a wide range of elasticities of substitution between durables and nondurables, this value of ω_d resolves the comovement problem. Alternatively, one could use evidence presented in Bils and Klenow (2004). They report that 29.8% of durables prices change in a month. This fraction implies an average duration of durables prices of 3 1/3 months, and so $\omega_d = 0.106$. For our estimated elasticity of substitution between durables and nondurables, 0.2563, there is no comovement problem; the same cannot be said for the Cobb-Douglas case ($\eta = 1$).

4. Conclusion

Two issues in the literature were addressed in this paper. First, the boom phase of a Pigou cycle must be broadly based, meaning in our model that in response to a nondurable sector news shock, both durables and nondurables output must rise. Second, the comovement problem, the tendency of many macroeconomic models to predict that output of durables and nondurables move in opposite directions following a monetary policy shock. These issues were addressed using a two sector New Keynesian model with staggered price setting. Price rigidities in the durables and nondurables sectors were calibrated to match microeconomic observations in Klenow and Malin (2011). Two factors were key to addressing the Pigou cycle and comovement problem literatures: (1) the estimated elasticity of substitution between durables and nondurables is considerably less than one, implying that these goods are complements in utility; and (2) price rigidities, particularly in the durable goods sector.

The model generates the boom phase of a Pigou cycle following a nondurable sector news shock. Price rigidities make firms forward-looking in their pricing behaviour. Since a positive news shock means that the future marginal cost of nondurables has fallen, nondurable goods firms start lowering their prices in advance of the realisation of the news shock. A further consequence of sticky prices is that the relative price of durables starts rising upon receipt of the news shock. Complementarity between durables and nondurables is an important ingredient to the study of Pigou cycles; complementarity implies that households are reluctant to substitute nondurables for durables. The net result is a business cycle boom in both sectors. Durable sector price rigidity is shown to be an important factor; when durables prices are less sticky, the durable sector experiences a bust in the period just prior to the realisation of the news shock. Monetary policy matters for Pigou cycles in the sense that when the interest rate response to inflation is sufficiently strong, or the response to output sufficiently weak, Pigou cycles do not occur. In these cases, the nondurable sector experiences a mild bust upon receipt of the news shock.

The model gives a partial resolution to the comovement problem in that it generates the right dynamics on impact: durables and nondurables move in the same direction. Durable sector price rigidity is important for helping to solve the comovement problem. That our model partially resolves the comovement problem even for quite modest degrees of durable sector price rigidity can be attributed to the fact that durables and nondurables are estimated to be complements in utility. For higher values of this elasticity, greater durable sector price stickiness is required to solve the comovement problem.

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