Nominal Rigidity, Monetary Policy and Expectation Driven Business Cycles

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Abstract

In this paper, I explore the effects nominal rigidities and monetary policies have on the generation of Pigou cycles, that is, business cycles driven by agents’ expectations of future technology. The optimal response of the central bank is analyzed under circumstances when agents receive a signal indicating the technology change in the future. To achieve these objectives, I introduce nominal rigidities and monetary policy into a standard two-sector model with non-durable and durable goods. The optimal reaction of the central bank is found by solving the Ramsey optimization problem. Furthermore, the Ramsey optimal policy can be approximated by simple operational policy rules. I find that nominal rigidities tend to amplify the responses to the expectation and monetary policies affect the expectation driven business cycles by affecting the real interest rate and user cost of durable goods. Another interesting result is that a simple policy rule reacting to the inflation rates in both non-durable and durable sector with appropriate weights can closely mimic the performance of the Ramsey policy.

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1. Introduction

The objectives of this paper are: (1) to study the effect of nominal rigidities and monetary policies on expectation driven business cycles (Pigou cycles); (2) to find the Ramsey optimal policy when agents in the economy receive a signal indicating future technology change. I am particularly interested in studying whether the central bank can mimic the Ramsey optimal policy with a relatively simple rule (one targeting only a few macroeconomic variables).

Beaudry and Portier (2004) formalized Pigou (1926)’s idea and defined Pigou cycles as: (i) agents receive signals or news indicating that technology will change in the near future and start to react, and (ii) later, the expectation does not realize, which leads to a reversion of previous reactions. The economy is said to be hit by a news shock. For example, an optimistic forecast of future technological improvement leads to a boom defined as an increase in aggregate output, employment, investment and consumption. When agents notice that their expectation does not realize, the economy incurs a recession defined as a fall in all the same aggregate variables. They also illustrate that standard one-sector and two-sector equilibrium models used in the macroeconomic literature can not produce Pigou cycles. Of course, their largest contribution is to find a particular multi-sector model in which Pigou cycles can arise. Their finding is that expectation driven business cycles can arise in neo-classical models when one allows for a sufficiently rich description of inter-sector production technology. In particular, the key
assumption giving rise to the Pigou cycles is that non-durable goods and durable goods exhibit enough complementarities in the production of the final goods.

In this paper, I formulate a dynamic general equilibrium model with two sectors that produce durable and non-durable goods respectively. One main difference between Beaudry and Portier’s model and mine is that nominal price rigidity and monetary policy are incorporated in my model. If prices are flexible, firms will adjust their prices only when the expected change in technology realized. By contrast, if firms cannot adjust their prices every period, they will start to adjust their prices once they receive the signal indicating a change in the technology. The price adjustment will happen before the realization of the technology change. The introduction of nominal rigidities causes the rise of the relative price of durable goods to non-durable goods before the realization of the news about the technology improvement in non-durable goods sector, which boosts the demand of non-durable goods. Barsky, House and Kimball (2007) pointed out that one of the features of two sector models with long-lived durable goods is that relative price is the key determinant of the demand of non-durable goods. Furthermore, if non-durable goods and durable goods are assumed to be complements, the boom in the non-durable goods sector could easily spread to the durable goods sector. So, the nominal rigidities amplify the extent of boom and bust when a news shock hits the economy.

The introduction of monetary policy also plays an important role in generating Pigou cycles. Central banks can have an impact on the real interest rate by controlling the nominal interest rate. Furthermore, agents’ decision of durable goods accumulation is
very sensitive to the change in the real interest rate. Notice that if the depreciation rate is small, the durable goods stock is much greater than durable goods production at each period. A small fluctuation in the durable goods stock translates into a much greater fluctuations in durable goods output and labor supply in this sector. The demand of durable goods is determined by the following two forces: it is affected by the demand of non-durable goods depending on whether they are complements or substitutes; in the meanwhile, it is also determined by the real interest rate controlled by the monetary policy. The interaction of these two forces determines the stock of durable goods and its production.

In this paper, I also explore the optimal reaction of the central bank to news shocks by solving the Ramsey optimization problem. The optimal reaction of the central bank is to raise the real interest rate to prevent agents from accumulating too much durable goods during the boom period when agents expect an improvement in the technology and lower the real interest rate to shorten the bust period after the agents’ expectations do not realize. Another interesting observation is that Ramsey policy fails to restore the outputs in both sectors to their potential levels, the output levels in the case of flexible prices. The main target of Ramsey policy is to restore the labor supply to its potential level by adjusting the production and labor inputs in durable goods sector. If central banks are assumed to be committed to simple implementable rules, the coefficients in the simple rules can be estimated using the simulated interest rates under the Ramsey policy. Comparing the impulse responses indicates that Ramsey optimal policy can be
approximated by a simple policy rule targeting inflation rates in both non-durable and durable sectors with appropriate weights.

This structure also allows me to study the following problem: is complementarity between non-durable goods and durable goods still a necessary condition to generate expectation driven business cycles after the introduction of nominal rigidities and monetary policy? My finding indicates that monetary policy plays an important role in generating Pigou cycles. In particular, a weak inflation targeting policy rule helps generate Pigou cycles without assuming complementarities between non-durable goods and durable goods.

The framework in this paper is closely related to the recent development of two sector models with nominal rigidities. 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, House and Kimball (2007) explored the comovements of non-durable and durable goods sectors responding to a monetary shock in a two sector model with nominal rigidities and long-lived durable goods. Erceg and Levin (2006) studied the optimal monetary policy in a two sector model with durable goods. They highlighted the distinction between the non-durable and durable sectors in that the durable goods sector is much more interest-sensitive than the non-durable sector. Monacelli (2006a,b) introduces collateral constraints into a two-sector model with non-durable and durable goods to study the comovements in these two sectors in response to
monetary policy shocks and optimal monetary issues.

Other related literatures include Christiano, Motto and Rostagno (2006) and Jaimovich and Rebelo (2006)’s research on the possibility of generating expectation driven business cycles in one sector models. They succeed in generating booms and busts of consumption, investment and output by adding investment adjustment costs, variable utilization of capital and habit persistence in preference 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, Motto and Rostagno (2006) extend their model by adding sticky prices, sticky wages and standard Taylor-rule monetary policies. Compared with their frameworks, my framework involves fewer real and nominal rigidities.

The remainder of this paper is organized as follows: section 2 outlines the dynamic general equilibrium model and defines the Ramsey optimal policy; section 3 describes the parameter calibration and solution methods; in section 4, experiments and simulations are conducted in models with three different features: the model with flexible prices, the model with nominal rigidities and exogenous money supply, and the model with nominal rigidities and Ramsey optimal policy. Through the comparison of the responses in these three cases, we can study the effect of nominal rigidities and monetary policies have on the generation of the Pigou cycles and explore the optimal policy reactions to the news shock; simulated interest rates under the Ramsey policy are used to estimate simple
interest rate rules in section 5; section 6 concludes.

2. The Model:

The economy is composed of two sectors: a non-durable goods sector and a durable goods sector. There are two types of firms in each sector: final goods firms produce final goods using intermediate goods; intermediate goods firms are monopolistic competitors that each produces a differentiated product using labor. These intermediate goods firms determine their prices following a Calvo-type staggered price adjustment. Households supply labor to both sectors and derive utility from consumption of non-durable final goods and services of durable final goods. The central bank conducts monetary policy.

Households

The household purchases a non-durable good $C_t$ and a durable good $D_t$ in the market and derives its utility from the consumption of a final good $X_t$. $X_t$ is defined as a CES composite of non-durable goods $C_t$ and durable goods $D_t$.

$$X_t = \left[ (1 - \alpha)^{\frac{1}{\eta}} (C_t)^{\frac{\eta-1}{\eta}} + \alpha^\eta (D_{t-1})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

(1)

where $\alpha$ is the share of durable goods in the composite consumption index. $\eta > 0$ is the elasticity of substitution between non-durable goods and durable goods. In the case $\eta \rightarrow 0$, non-durable goods and durable goods are perfect complements; whereas if $\eta \rightarrow \infty$, the two goods are perfect substitutes.

The household maximizes the following expected utility
\[ E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U(X_t, N_t) \right\} \]  

(2)

Where \( U(X_t, N_t) = \log(X_t) - \frac{N_t^{\beta+1}}{1 + \sigma} \)

Subject to the budget constraint (in nominal terms):

\[ P_{c,t} C_t + P_{d,t} (D_t - (1 - \delta)D_{t-1}) + B_t + M_t = R_{t-1}B_{t-1} + W_t N_t + M_{t-1} + T_t + \Pi_{c,t} + \Pi_{d,t} \quad (3) \]

Where \( N_t \) is total labor supply; \( B_t \) is end-of-period \( t \) nominal bond; \( R_{t-1} \) is the nominal interest rate on the bond stipulated at period \( t-1 \); \( M_t \) is nominal money balances held; \( W_t \) is the nominal wage. Labor is assumed to be perfectly mobile across sectors, implying that the nominal wage rate is common across sectors. \( \Pi_{c,t} \) and \( \Pi_{d,t} \) are the dividends received from the ownership of intermediate firms in both sectors. \( T_t \) is lump-sum transfers net of taxes.

The household chooses \( \{N_t, B_t, D_t, C_t\} \) to maximize (2) subject to (3). Defining \( \lambda_t \) as the Lagrangian multiplier associated with constraint (3), and \( U_{k,t} \) \((k \in \{C, N, D\})\) as the marginal utility of respective variable, first order conditions for household’s decision problem read:

\[ -\frac{U_{n,t}}{U_{c,t}} = \frac{W_t}{P_{c,t}} \quad (4) \]

\[ q_t U_{c,t} = U_{d,t} + \beta(1 - \delta)E_t(U_{c,t+1} q_{t+1}) \quad (5) \]

\[ 1 = \beta E_t \left( R_t \frac{U_{c,t+1}}{U_{c,t}} \frac{P_{c,t}}{P_{c,t+1}} \right) \quad (6) \]

where \( q_t = \frac{P_{d,t}}{P_{c,t}} \) is the relative price of the durable good; Equation (4) links the real wage
to the household’s marginal rate of substitution between consumption and leisure. Equation (5) requires that the household equates the marginal utility of current non-durable consumption to the marginal gain of durable services. The marginal gain of durable services includes two parts: (i) the direct utility gain of an additional unit of durable; (ii) the expected utility stemming from the consumption of the resale value of the durable purchased in previous period. Equation (6) is the Euler condition. The term \( \beta \frac{U_{c,t+1}}{U_{c,t}} \) is defined as stochastic discount factor \( \Delta_t \).

Barsky, House and Kimball (2007) pointed out that one feature of the two sector model with long-lived durable goods is that the shadow price of the durable goods is approximately constant following a temporary shock, which can be shown in the following equation:

\[
\gamma_t = q_t U_{c,t} = U_{d,t} + \beta (1 - \delta) E_t(U_{d,t+1}) + \beta^2 (1 - \delta)^2 E_t(U_{d,t+2}) + ... 
\]

where \( \gamma_t \) is the shadow value of the durable goods. For a highly durable good, the ratio of stock to flow is very high. Even large fluctuations in the purchases of the durable goods have only minor effects on the stock. It is reasonable to treat the shadow value of durable goods as roughly constant in response to a news shock, since news shock only causes a temporary and modest deviation of the durable goods stock from the steady state. From (7), it is straightforward to show that the marginal utility of non-durable goods, and thus the consumption of non-durable good are determined by the price of the durable good relative to the price of the non-durable good.
Combining (5) and (6), (5) can be rewritten as
\[
\lambda_i q_i - (1 - \delta) \frac{E_i(q_{i,t+1})}{R_t/E_i(\pi_{c,t+1})} = \lambda_i u_{c_i} = U_{d,t} \tag{8}
\]
where \( R_t/E_i(\pi_{c,t+1}) \) is the real interest rate in non-durable goods sector. The term in the brace is defined as the user cost of durable goods. For one unit of durable goods, user purchases it at the price \( q_i \). Next period, after the depreciation, the remaining durable goods stock \( 1 - \delta \) can be sold at price \( q_{t+1} \). Then, the user cost is the purchasing price of durable goods minus the present value of resale revenue.

To clearly see the determinant of the stock of the durable goods, we transform (8) as follows:
\[
\lambda_i q_i [1 - \frac{(1 - \delta)}{R_t/E_i(\pi_{d,t+1})}] = \gamma_i [1 - \frac{(1 - \delta)}{R_t/E_i(\pi_{d,t+1})}] = U_{d,t} \tag{9}
\]
where \( R_t/E_i(\pi_{d,t+1}) \) is the real interest rate in durable goods sector. Since the shadow value of the durable goods can be treated roughly constant, the marginal utility of durable goods, and thus the stock of the durable goods are roughly determined by the real interest rate in durable goods sector\(^1\).

**Final Good Producers**

In each sector \( j (j \in \{c,d\}) \), where \( c \) denotes the non-durable sector and \( d \) denotes the durable sector), a perfectly competitive final good producer purchases \( Y_{j,t}(i) \) units of intermediate good \( i \). The production function that transforms intermediate goods into

\(^1\) The stock of durable goods is also affected by the consumption of the non-durable goods depending on the assumption of complementarity or substitution between these two goods.
final good is given by

$$Y_{j,t} = \left\lfloor \int_0^1 Y_{j,t}(i)^{\frac{\varepsilon_j}{\varepsilon_j - 1}} di \right\rfloor^{\frac{\varepsilon_j}{\varepsilon_j - 1}}$$  \hspace{1cm} (\varepsilon_j > 1, \ j = c, d) \quad (10)$$

where $\varepsilon_j$ is the elasticity of substitution between differentiated intermediate goods in sector $j$.

Demand functions for intermediate good $i$ in sector $j$ can be derived from the following cost minimization problem: choose $Y_{j,t}(i)$ to minimize

$$\int_0^1 P_{j,t}(i) Y_{j,t}(i) di$$  \hspace{1cm} (11)$$

subject to

$$\left[ \int_0^1 Y_{j,t}(i)^{\frac{\varepsilon_j}{\varepsilon_j - 1}} di \right]^{\frac{\varepsilon_j}{\varepsilon_j - 1}} \geq Y_{j,t}$$  \hspace{1cm} (12)$$

It is straightforward to show that demand function for intermediate good $i$ in sector $j$ is

$$Y_{j,t}(i) = \left( \frac{P_{j,t}(i)}{P_{j,t}} \right)^{1-\varepsilon_j} Y_{j,t} \quad (j = c, d) \quad (13)$$

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

**Intermediate Goods Producers**

In both of the non-durable and durable sectors, there is a continuum of monopolistically competitive intermediate goods producers indexed by $i \in [0,1]$. Each intermediate goods producer faces the demand curve (13) for its product. It uses only labor to produce output according to the following technology.
\[ Y_{j,t}(i) = A_{j,t} N_{j,t}(i) \]  

where \( A_{j,t} \) is the technology in sector \( j \). \( N_{j,t}(i) \) is the labor hired by firm \( i \) in sector \( j \).

Intermediate goods producers set nominal prices on a staggered basis. Following Calvo (1983), firms are assumed to adjust their prices infrequently and that opportunities to adjust arrive following an exogenous Poisson process. Each period, there is a constant probability \( 1 - \omega_j \) that the firm can adjust its price, the remaining \( \omega_j \) fraction keep their prices fixed.

When a firm gets a chance to adjust its price, it sets the price \( p_{j,t}^* \) to maximize the following expected discounted profit

\[
E_t \sum_{i=0}^{\infty} \omega_j^i \Delta_{t+i} \left[ \left( \frac{p_{j,t}^*}{p_{j,t+i}} \right) Y_{j,t+i} - MC_{j,t+i} Y_{j,t+i} \right]
\]

where \( \Delta_{t+i} = \prod_{s=t}^{t+i} \Delta_s \), \( \Delta_t \) is the stochastic discount factor defined in household’s decision problem; \( MC_{j,t+i} = \frac{W_i}{A_{j,t} P_{j,t}} \) is the real marginal cost. When a firm gets a chance to adjust price at period \( t \), it has to take into account that this new price will remain unchanged until period \( t+i \) with a probability \( \omega_j^i \). The term in the square bracket denotes the firm’s profit (in real terms) at period \( t+i \) if it does not get a chance to adjust its price. Note that each firm adjusting its price at period \( t \) faces the same profit maximization problem in (15), so all firms will set the same price \( p_{j,t}^* \).

Using the definition of \( \Delta_{t+i} \) and demand curve in (13), it is straightforward to derive \( p_{j,t}^* \) from the maximization of (15).
The sector $j$'s price index satisfies

$$P_{j,t} = [(1 - \omega_j)(p^*_{j,t})^{1-\epsilon_j} + \omega_j P_{j,t-1}^{1-\epsilon_j}]^{\frac{1}{1-\epsilon_j}}$$  \hfill (17)

The sectoral inflation rate $\pi_{j,t} = \frac{P_{j,t}}{P_{j,t-1}}$.

Final consumption good $X_t$'s price index satisfies

$$P_t = [(1 - \alpha)P_{e,t}^{1-\eta} + \alpha P_{d,t}^{1-\eta}]^{\frac{1}{1-\eta}}$$  \hfill (19)

The CPI inflation $\pi_t = \frac{P_t}{P_{t-1}}$.

News Shocks

News shocks are modeled following Christiano, Motto and Rostagno (2006). Up until period $t$, the economy is at a steady state. In period $t$, a signal arrives that suggests technology in sector $j$ will improve in period $t+p$. Then, in period $t+p$, the expected rise in technology in fact does not occur. A time series representation for productivity which captures this unrealized optimistic expectation is:

$$\log(A_{j,t}) = \rho_j \log(A_{j,t-1}) + \epsilon_{j,t-p} + \zeta_{j,t}$$  \hfill (21)
indicating that productivity will increase at period $t$, that is, $\varepsilon_{j,t-p}$ has a high value. This shifts up the expected value of $\log(A_{j,t})$. However, at period $t$, if the realization of $\zeta_{j,t} = -\varepsilon_{j,t-p}$, then the high expected value of $\log(A_{j,t})$ does not materialize. In this case, $\varepsilon_{j,t-p}$ turns out to be not informative. If the realization of $\zeta_{j,t}$ is zero, then the high expected value of $\log(A_{j,t})$ does materialize. In this case, the signal $\varepsilon_{j,t-p}$ is perfectly informative. In general, $\varepsilon_{j,t}$ and $\zeta_{j,t}$ are assumed to be drawn from normal distribution $N(0, \sigma_\varepsilon)$ and $N(0, \sigma_\zeta)$ respectively. The implications of various realizations of $\varepsilon_{j,t}$ and $\zeta_{j,t}$ are shown in table 1.

Table 1 The implications of various realizations of $\varepsilon_{j,t}$ and $\zeta_{j,t}$

<table>
<thead>
<tr>
<th>Different combination of $\varepsilon_{j,t}$ and $\zeta_{j,t}$</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_{j,t} &gt; 0$, $\zeta_{j,t} = 0$</td>
<td>High expectation fully realized</td>
</tr>
<tr>
<td>$\varepsilon_{j,t} &gt; 0$, $-\varepsilon_{j,t} &lt; \zeta_{j,t} &lt; 0$</td>
<td>High expectation partially realized</td>
</tr>
<tr>
<td>$\varepsilon_{j,t} &gt; 0$, $\zeta_{j,t} = -\varepsilon_{j,t}$</td>
<td>High expectation not realized at all</td>
</tr>
<tr>
<td>$\varepsilon_{j,t} &gt; 0$, $\zeta_{j,t} &lt; -\varepsilon_{j,t}$</td>
<td>Agents expect a rise in TFP, actually the TFP drops</td>
</tr>
<tr>
<td>$\varepsilon_{j,t} &gt; 0$, $\zeta_{j,t} &gt; 0$</td>
<td>TFP rises more than expected</td>
</tr>
</tbody>
</table>

For the purposes of solving and simulating the model, it is useful to specify the evolution of the exogenous shocks as:

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1 I only list the situations where agents expect a rise in TFP.
At equilibrium, households choose $N_t, C_t, D_t, B_t$ that satisfies first order conditions (4)-(6), taking goods prices, wage rate and interest rate given; intermediate goods firms in sector $j$ choose prices to maximize the expected discounted profits (15), then decide the labor inputs $N_{j,t}$ to meet the demand for their products; final goods producers decide the purchase of intermediate goods based on the demand function (13). In the meanwhile, all markets should clear:

Market clear in non-durable goods market: $Y_{c,t} = C_t$ \hspace{1cm} (23)

Market clear in durable goods market: $Y_{d,t} = D_t - (1 - \delta)D_{t-1}$ \hspace{1cm} (24)

where $Y_{j,t} = \int_0^1 Y_{j,t}(i) di = A_{j,t} \int_0^1 N_{j,t}(i) di = A_{j,t} N_{j,t}$ \hspace{0.5cm} ($j \in \{c, d\}$)

Market clear in labor market: $N_t = N_{c,t} + N_{d,t}$ \hspace{1cm} (25)

A monetary policy is still needed to complete the model.

**Exogenous Monetary Supply Rule**

To highlight the effects of different money policies on the responses to news about the future technology change, an exogenous monetary supply rule is added to the model as a baseline case. Money is injected into the economy through lump sum transfer $T_t$. Money demand is assumed to be proportional to nominal purchases:

\[
\begin{pmatrix}
\log(A_{j,t}) \\
\varepsilon_{j,t} \\
\epsilon_{j,t-1} \\
\vdots \\
\epsilon_{j,t-p+1}
\end{pmatrix}
= 
\begin{pmatrix}
\rho_j & 0 & \cdots & 0 & 1 \\
0 & 0 & \cdots & 0 & 0 \\
0 & 1 & \cdots & 0 & 0 \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
0 & 0 & \cdots & 1 & 0
\end{pmatrix}
\begin{pmatrix}
\log(A_{j,t-1}) \\
\varepsilon_{j,t-1} \\
\epsilon_{j,t-2} \\
\vdots \\
\epsilon_{j,t-p}
\end{pmatrix}
+ 
\begin{pmatrix}
\varepsilon_{j,t} \\
0 \\
0 \\
\vdots \\
0
\end{pmatrix}
\]

(22)
Money supply is assumed to follow an exogenous supply rule:

\[ M_t = M_{t-1} + \xi_t \quad (27) \]

where \( \xi_t \) is a zero mean i.i.d disturbance.

**Ramsey Optimal Monetary Policy**

Alternatively, central bank is assumed to follow a Ramsey optimal monetary policy using interest rate as a policy instrument. The Ramsey approach to study optimal policy is mainly used in the field of public finance. Recently, researchers begin to adopt this approach to characterize optimal monetary policies in models with nominal rigidities. For example, Levin, Onatski, Williams and Williams (2005) investigate the design of monetary policy when the central bank faces uncertainty about the true structure of the economy. They find the optimal policy regime that maximizes household welfare using Ramsey approach and then evaluate the performance of alternative simple policy rules relative to this benchmark.

The Ramsey optimal policy under commitment can be computed by formulating an infinite horizon Lagrangian problem, in which the central bank maximizes the conditional expected social welfare subject to the full set of non-linear constraints implied by the private sector's behavioral equations and the market-clearing conditions of the model economy.

In the case of my model, the central bank’s optimization problem can be described as

\[ M_t = P_{c,t} C_t + P_{d,t} (D_t - (1 - \delta) D_{t-1}) \quad (26) \]
\[
\max E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U(X_t, N_t) \right\}
\]

Subject to (4)-(6), (16) and (23)-(25).

Solving this problem generates the first order conditions that characterize the Ramsey optimal policy\(^3\). These first order conditions are bundled together with the private sector's behavioral equations and the market-clearing conditions to analyze the behavior of the economy under the Ramsey optimal policy.

3. Calibration and Solution

The model is calibrated at a quarterly frequency. Some parameter values are typical in the business cycle literature. The discount factor $\beta$ is set to be 0.99, consistent with a steady state annualized real interest rate of about 4%. The quarterly depreciation rate of the durable stock $\delta$ is set to 0.025, implying an annual depreciation rate of 10%. $\alpha$, the parameter in the composite consumption index $X_t$, can be chosen so that the steady state share of durable goods output in total output is 0.25. The parameter $\sigma$ is set to be 1 so that the elasticity of labor supply is unity. The parameter $\nu$ in the utility function is set so that steady-state labor supply is 1/3. The autoregressive coefficient in the productivity process $\rho$ is set to 0.95. The standard deviations of signal term $\varepsilon_{j,t}$ and revision term $\zeta_{j,t}$ in the technology process are assumed to be 0.01 respectively. The technology innovation in the model is a combination of a signal term $\varepsilon_{j,t}$ and a revision term $\zeta_{j,t}$, and

\(^{3}\) Dynare-Matlab procedures developed by Levin and Lopez-Salido (2004) are used to derive these first order conditions.
and are assumed to be uncorrelated with each other, which indicates that the standard deviation of the technology innovation can be calculated as $\sqrt{\sigma_{e}^2 + \sigma_{\zeta}^2} = 0.0141$.

Following Beaudry and Portier (2004), the elasticity of substitution between non-durable goods and durable goods, $\eta$, is set to be 0.2 in the baseline case, implying a strong complementarity between the non-durable goods and durable goods.

The parameter $\omega_j$ determines how long a price contract will last. The empirical evidence surveyed by Taylor (1999) suggests that nominal price contracts on average last for a year, implying $\omega_j = 0.75$. Bils and Klenow (2004) argue that the observed frequency of price adjustment in the U.S. is much higher, or in the order of two quarters, implying $\omega_j = 0.5$. In recent literatures of two-sector models with nominal rigidities, Erceg and Levin (2006) assumed symmetric price rigidities in non-durable and durable sectors. Barsky, House and Kimball (2007) and Monacelli (2006b) studied the cases with asymmetric price rigidities. They argued that the prices of durable goods adjust more frequently than non-durable goods in that the menu cost relative to the unit price of durable goods is much lower. I set $\omega_j = 0.75$ for both sectors in the baseline calibration, but allow for asymmetric price rigidities in the approximation of the Ramsey policy.

The parameters $\varepsilon_j$ ($j \in \{c, d\}$) measure the elasticity of substitution between differentiated intermediate goods. Following Monacelli (2006b), I set both parameters to 8, which yields a steady state mark-up of 15% for intermediate goods producers.

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4 The expected time between price adjustments is $1/(1 - \omega_j)$
The values of all the baseline parameters are summarized in table 2.

The model is solved by taking a log-linear approximation of the equilibrium conditions in the neighborhood of the steady state\(^5\).

4. Simulation Results

In this section, responses to the news about the future technology improvement are explored in three cases: model with an exogenous money supply rule, model with a Ramsey optimal policy and model with flexible prices. Through the comparison of the responses in these three cases, we can highlight the effects of adding nominal rigidities and different monetary policies on the responses to a news shock. In each of three cases, we focus on the comovements of non-durable goods sector and durable goods sector. The key problem is whether the model can generate a boom of production in both sectors after agents receive the news about the future technology improvement.

Agents are assumed to receive a signal at period t suggesting technology in sector \(j\), \(A_j\), will be increased by 1% at period \(t+4\), that is, a high \(\varepsilon_{j,4}\) leads to an upward revision in the expectation of \(\log(A_{j,5})\). In period 1, agents will act on that expectation. In period 5, the realization of \(\log(A_{j,5})\) is determined by the realization of \(\zeta_{j,5}\). If it happens that \(\zeta_{j,5} = -\varepsilon_{j,1}\), then the expected positive move in \(\log(A_5)\) does not occur. Following Beaudry and Portier (2004), I first assume that agents receive a signal suggesting the technology will increase in the non-durable sector.

\(^5\) Dynare-Matlab has been used to solve the model. For details of Dynare, refer to http://www.cepremap.cnrs.fr/dynare/.
4.1 Responses under flexible prices

Solid line in figure 1 illustrates the responses to a news shock described above. Household starts to accumulate durable goods immediately after they receive the signal about the future technology improvement in non-durable sector, which boost the production of durable goods and the labor demand in that sector. In the meanwhile, the total labor supply does not rise as much as the labor demand in durable sector, which causes a drop in non-durable goods production. The relative price remains unchanged in the model with flexible prices due to the fact that both the prices of durables and non-durables are a constant markup over the marginal costs, which is the ratio of the wage to the marginal product. In my model, marginal product of labor is just the technology level and wage is assumed to be equal in two sectors. As long as the technology does not change, the relative price will remain unchanged.

In a similar two sector model without any nominal rigidities, Beaudry and Portier (2004) succeed in generating the positive comovements of non-durable goods and durable goods and increase of the relative price after agents receive news about future technology improvement. Two differences between their model and the one presented in this paper can explain the discrepancy. First, Beaudry and Portier assumed a decreasing marginal product of labor while I assumed a constant one. With a decreasing marginal product of labor, the marginal cost in durable sector increases when labor employed in durable goods sector rises, which causes the increase in the relative price. The increase in the price of the durable goods relative to the non-durable goods dampens the incentive to
accumulate the durable goods and boosts the demand of non-durable goods, which helps generating the positive comovements. Second, as pointed out in Beaudry and Portier, an infinite elasticity of labor supply assumed in their model also helps generating the positive comovements.

4.2. Responses under exogenous money supply rule

The lines with circles in figure 1 show the responses to the news about the future technology improvement in the model with nominal rigidities and an exogenous money supply. Outputs, labor supplies and relative price experience a boom after agents receive a signal indicating the future technology improvement in non-durable sector and a bust when the expectation is not realized. Comparing the responses in the model with nominal rigidities with those with flexible prices, it is clear that nominal rigidities play an important role in generating the rise of relative price and the positive comovements of non-durable goods and durable goods. The underlying mechanism is as follows: sticky price producers decide their prices based on the weighted average of the current and future marginal costs. Non-durable goods producers expect that the marginal costs will drop in the future due to the technology improvements and starts to lower their prices once they obtain the chance of price adjustment, which causes a rise in the relative price. The low price of non-durable goods boosts the demand of non-durable goods and also spurs the demand of durable goods due to the assumed complementarity between non-durable and durable goods. As pointed out in Barsky, House and Kimball (2007), one of the features of the two sector models with long-lived durable goods is that the demand of
non-durable goods is determined by the relative price. The comovement of non-durable goods production and the relative price in figure 1 is consistent with their conclusion. In sum, the introduction of nominal rigidities causes the rise of the relative price, and thus the boom of the non-durable goods consumption, which amplifies the responses to the news shock.

4.3. Responses under Ramsey optimal policy

The lines with stars in Figure 1 demonstrate the impulse responses to a news shock when the central bank employs the Ramsey optimal policy. To highlight the effect of the Ramsey optimal monetary policy on the responses, we focus on the comparison the responses under the exogenous money supply and those under the Ramsey policy. First, outputs, labor supplies and relative price experience a boom when agents expect a rise of technology in the non-durable sector and a bust when the optimistic expectation does not materialize. It seems that Ramsey monetary policy does not have any effect on the movement of relative price\(^6\), which determines that the response of output of non-durable goods is similar to that under the exogenous money supply. However, the rise in the output of durable goods is much less than that under the exogenous money supply. This difference could be attributed to the rise of the nominal interest rate suggested by the Ramsey policy. If central bank follows the Ramsey optimal policy, the annualized nominal interest rate should be raised to about 4.35% (steady state 4%) in the boom

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\(^6\) This is true only when the degrees of nominal rigidities are assumed to be the same in two sectors. When asymmetric nominal rigidities are assumed, monetary policy has some effect on the relative price.
periods and immediately drops to about 3.9% once agents realize that their expectations do not realize. The rise in the nominal interest rate boosts the real interest rate in durable goods sector and the user cost of durable goods, which dampens the demand of durable goods. The demand of durable goods is determined by two forces: complementarity between non-durable goods and durable goods pushes the demand up, while the rise of the user cost pushes the demand down. The combination of these two forces is that the demand of durable goods rises by a moderate amount.

Comparing the responses under Ramsey policy and those under flexible prices, we can observe that optimal Ramsey policy cannot restore the economy to flexible price situations. There must be some trade off here so that the Ramsey policy cannot remove the distortion caused by the nominal rigidities. First, consumption of non-durable goods is almost determined by the relative price. Monetary policy has no impact on the relative price and hence no impact on the consumption of non-durable goods. So, no matter what monetary policy rule central bank applies, the relative price of durable goods and consumption of non-durable goods will increase when agents expect an improvement in technology in non-durable sector. Second, if Ramsey policy tries to restore the combination of non-durable goods and durable goods to the flexible price level, the durable goods production must be reduced by a tremendous magnitude due to the large ratio of stock to flow, which will push the total labor supply quite below the flexible price level. Third, if Ramsey policy tries to restore the total labor supply to flexible price level, labor has to move from durable goods sector to non-durable goods sector, which causes a
lower output of durable goods. However, the stock of durable goods is almost unchanged due to the large ratio of stock to flow. In this case, Ramsey policy fails to restore the combination of non-durable goods and durable goods, \( X_t \), to flexible price level. In sum, it is impossible for Ramsey policy to restore both the combination \( X_t \) and the total labor supply to the flexible price situation. Faced with this tradeoff, the only objective the Ramsey optimal policy can achieve is to make the labor supply as close to the flexible price level as possible. The Ramsey policy chooses to raise the nominal interest rate so that the real interest rate and user cost of durable goods increase. This reduces the incentive to accumulate durable goods and the production of durable goods so that labor can be shifted to the booming non-durable goods sector.

The lines with stars in Figure 2 show the responses to the news about the future technology improvement in non-durable sector and realization of that news, assuming Ramsey optimal policy is employed. The nominal interest rate will be lowered gradually after the news shock is realized. Consequently, the demand of durable goods increases, which causes the hike of the durable goods production. The boom in durable sector absorbs the extra labor from the non-durable sector after the realization of the technology improvement. So, the Ramsey policy smoothes the total labor supply by suppressing the production in durable sector before the realization of the news and unleash the constraint after the realization.

4.4 Model features helps generating boom and bust
Beaudry and Portier (2004) attributes the success of generating Pigou cycles to the following features of their model: (1) the complementarity between non-durable goods and durable goods; (2) an expectation of technology improvement in non-durable sector instead of durable sector. To see whether these features are still indispensable in generating Pigou cycles in my model, I change these features of the model to alternative ones and compare the differences of impulse responses under alternative assumptions.

First, I change the elasticity of substitution between non-durable goods and durable goods, $\eta$, from 0.2 to 0.9999 and keep the other parameters in the model unchanged. In this case, the households produce the final goods through a Cobb-Douglas production function. The IRFs in figure 3 indicate that the economy does not respond to the news in the case of flexible prices. When the prices are rigid and an exogenous money supply rule is employed, the news about the future technology improvement in non-durable goods sector only have an impact on non-durable goods sector. Only under the circumstance of Ramsey policy, both of two sectors respond to the news, however, the comovement of non-durable goods and durable goods is negative. The underlying mechanism is: non-durable goods producers expect a drop in future’s marginal costs and start to lower the price, which lead to a rise of the relative price and the demand of the non-durable goods. As Ramsey policy lacks the ability to restore the combination of non-durable goods and durable goods to its flexible price level, it focuses on restoring the labor supply to its flexible level. A central bank following the Ramsey optimal policy will raise the nominal interest rate and causes a rise in the real interest rate and user cost of durable goods.
Consequently, the production in durable goods sector slumps and the redundant labor is taken over by the booming non-durable sector. This experiment verifies that complementarity between non-durable goods and durable goods still plays a significant role in generating Pigou cycles in a two-sector model.

Next, I assume that agents receive a signal suggesting a technology rise in the durable sector instead of non-durable sector. The impulse responses in Figure 4 are also consistent with Beaudry and Portier’s result: macro aggregates move downwards together when agents expect a rise of technology in durable sector. Since agents expect that there is a technology improvement in the durable sector and the relative price of durable goods will drop in the future, they would rather postpone the investment in durable sector until the realization of the technology improvement. This observation verifies that the assumption that agents receive signals about improvements in the non-durable sector is essential to generate Pigou cycles.

5 Approximate Ramsey policy using simple policy rules

5.1. Baseline parameters

Following Taylor (1993), numerous researches have estimated or evaluated a multitude of simple monetary policy rules. The policies are simple in the sense that they involve only a few observable macroeconomic variables. In terms of maximizing agents’ welfare, the performances of simple rules are inferior to that of Ramsey optimal policy since simple rules only react to a few selected observable variables. However, simple
rules are easier to explain to the public, so it appears more transparent. To see whether the nominal interest rate associated with Ramsey policy can be approximated by a simple policy rule, I estimate the following regressions using artificial time series generated from the model:

\[
R_t = \alpha_0 + \alpha_1 \pi_t + \alpha_2 x_t + \epsilon_t \quad (28)
\]

\[
R_t = \beta_0 + \beta_1 \pi_{c,t} + \beta_2 \pi_{d,t} + \beta_3 y_{c,t} + \beta_4 y_{d,t} + \epsilon_t \quad (29)
\]

where \( R_t \) is the annualized nominal interest rate, \( \pi_t \) is the CPI inflation rate and \( x_t \) is the output gap measured as the percentage deviation of final consumption good \( X_t \) from its steady state, \( \pi_{c,t} \) and \( \pi_{d,t} \) are annualized inflation rates in non-durable and durable sector respectively, \( y_{c,t} \) and \( y_{d,t} \) are output gaps in non-durable and durable sector measured as percent deviation from the steady state. Equation (28) is the original Taylor rule specification. The objective of estimating (29) is to see the additional benefit of targeting sectoral inflation and output gap. To generate artificial time series, shocks \( \epsilon_t \) and \( \zeta_t \) are drawn from the normal distribution, then time series of size 1000 for \( R_t, \pi_t, x_t, \pi_{c,t}, \pi_{d,t}, y_{c,t}, y_{d,t} \) are generated using the decision rules.

The OLS estimate of the simple rule (27) is:

\[
R_t = 4.036 + 1.222 \pi_t - 0.013 x_t, \quad R^2 = 0.987 \quad (30)
\]

The OLS estimate of the simple rule (28) is:

\[
R_t = 4.033 + 0.019 \pi_{c,t} + 0.997 \pi_{d,t} - 0.0064 y_{c,t} - 0.0014 y_{d,t}, \quad R^2 = 0.994 \quad (31)
\]

Both of these two estimated simple rules fit quite well the Ramsey policy. It seems that targeting sectoral inflation and output gaps does not bring significant additional
benefit\(^7\). Estimated simple rule (30) does not resemble the Taylor rule in that the coefficient on output gap is negative. The coefficient on inflation is greater than 1, which indicates that central bank raises nominal interest rate more than the inflation rate to ensure an increase in the real interest rate. Figure 5 shows the impulse responses of selected variables under the Ramsey optimal policy and the estimated rule (30).

5.2. Asymmetric nominal rigidities

Through the above experiments, we observe that an estimated simple rule can approximate the Ramsey policy quite well in the case of baseline parameters. In this section, sensitive analysis is conducted to explore how the interest rate reaction function will change under alternative parameters. In the baseline calibration, I assume symmetric nominal rigidity in two sectors. Since I am not certain about the degree of nominal rigidities in both sectors, I will do an experiment to see how optimal monetary policy will change when the frequencies to reset the prices \((\omega_j, j = c, d)\) are different between non-durable sector and durable sector. This experiment also shows how the central bank decides the weights given to each sector when the optimal policy is to target the inflation rates of both sectors. In this experiment, all the parameters will remain the baseline value except for the degree of nominal rigidity.

Table 3 lists the estimation results of simple policy rules defined in (28) and (29). First, in general, the estimated policy rules fit the Ramsey policy closely. However, the fit

\(^7\) Targeting sectoral inflation and output gap will bring additional benefit when asymmetric nominal rigidity is assumed in the next subsection.
becomes worse when the asymmetry of nominal rigidities gets larger. Second, the improvement in fit of reacting to sectoral inflation and output gaps become more and more significant with the increase in the asymmetry of nominal rigidities. Third, when the nominal rigidities are symmetric in two sectors, Ramsey optimal policy almost targets the inflation in durable sector only; when the nominal rigidity in non-durable sector becomes greater relative to that in durable sector, more weight will be given to inflation in non-durable sector. To see this trend more clearly, I estimate another form of simple rule that only reacts to inflation in both sectors. The results in table 4 shows a clear shift of weights from durable sector inflation to non-durable sector inflation as the nominal rigidity in non-durable sector becomes relatively greater. Another interesting result is that it only loses a little fit by targeting only inflations compared with targeting both the inflation and output gap. Figure 6 shows the impulse responses of selected variables under Ramsey optimal policy and estimated simple rules.

Table 3 Estimation of simple policy rules (28) and (29)

<table>
<thead>
<tr>
<th>Nominal rigidity</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>$\beta_3$</th>
<th>$\beta_4$</th>
<th>$R^2$</th>
<th>$\alpha_1$</th>
<th>$\alpha_2$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_e = 0.75, \omega_d = 0.75$</td>
<td>0.019</td>
<td>0.997</td>
<td>-0.0064</td>
<td>-0.0014</td>
<td>0.997</td>
<td>1.222</td>
<td>-0.013</td>
<td>0.985</td>
</tr>
<tr>
<td>$\omega_e = 0.75, \omega_d = 0.5$</td>
<td>0.397</td>
<td>1.027</td>
<td>0.037</td>
<td>-0.062</td>
<td>0.965</td>
<td>0.944</td>
<td>-0.049</td>
<td>0.941</td>
</tr>
<tr>
<td>$\omega_e = 0.75, \omega_d = 0.4$</td>
<td>1.902</td>
<td>0.991</td>
<td>0.031</td>
<td>-0.059</td>
<td>0.901</td>
<td>0.839</td>
<td>-0.072</td>
<td>0.869</td>
</tr>
<tr>
<td>$\omega_e = 0.75, \omega_d = 0.3$</td>
<td>4.734</td>
<td>0.921</td>
<td><strong>0.020</strong></td>
<td>-0.094</td>
<td>0.813</td>
<td>0.686</td>
<td>-0.116</td>
<td>0.725</td>
</tr>
<tr>
<td>$\omega_e = 0.75, \omega_d = 0.25$</td>
<td>10.11</td>
<td>0.890</td>
<td><strong>0.009</strong></td>
<td>-0.080</td>
<td>0.736</td>
<td>0.633</td>
<td>-0.145</td>
<td>0.617</td>
</tr>
</tbody>
</table>

Note: underscored coefficients are not significant at 5% significance level.
Table 4 \( R_t = \beta_0 + \beta_1 \pi_{c,t} + \beta_2 \pi_{d,t} + u_t \)

<table>
<thead>
<tr>
<th>Nominal rigidity</th>
<th>( \beta_1 )</th>
<th>( \beta_2 )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \omega_c = 0.75, \omega_d = 0.75 )</td>
<td>0.013</td>
<td>0.985</td>
<td>0.992</td>
</tr>
<tr>
<td>( \omega_c = 0.75, \omega_d = 0.5 )</td>
<td>0.678</td>
<td>0.903</td>
<td>0.941</td>
</tr>
<tr>
<td>( \omega_c = 0.75, \omega_d = 0.4 )</td>
<td>2.219</td>
<td>0.887</td>
<td>0.882</td>
</tr>
<tr>
<td>( \omega_c = 0.75, \omega_d = 0.3 )</td>
<td>6.289</td>
<td>0.836</td>
<td>0.768</td>
</tr>
<tr>
<td>( \omega_c = 0.75, \omega_d = 0.25 )</td>
<td>11.78</td>
<td>0.830</td>
<td>0.712</td>
</tr>
</tbody>
</table>

The results in table 4 suggests that the Ramsey optimal policy puts much more weight on the durable sector inflation when the degree of nominal rigidities are the same in the two sectors or even when the degree of nominal rigidity in non-durable good sector is moderately larger. Notice that the relative share of durable good output to non-durable good output is 1 to 3. So, even when the coefficient on the non-durable good inflation is three times that of the durable good inflation in the interest rate reaction function, we can still say that the policy puts the same weight on the two sectors. Only when the degree of nominal rigidity is much larger in the non-durable good sector than in durable good sector (e.g. \( \omega_c = 0.75, \omega_d = 0.3 \)), does the optimal policy begin to put more weight on non-durable sector inflation.

5.3 What if central bank follows a weakly inflation target rule

In this subsection, I did an experiment to study the responses of economy to a news shock if the central bank employs a simple rule with the coefficients of inflation different
with those estimated using Ramsey optimal policy. In particular, I set the policy reaction function as:

\[ R_t = R_{ss} + 1.01\pi_t \]  

(32)

compared with the estimated rule in (30), the interest rate in simple policy rule (32) only weakly reacts to inflation. To highlight the effect of monetary policy on the generation of Pigou cycles, non-durable goods and durable goods are assumed to be substitutes \((\eta = 2)\). Figure 7 shows the impulse responses of selected variables under both of the Ramsey policy and weakly inflation-targeting (WIT) rule defined in (32). The most interesting observation is that Pigou cycles can arise when the central bank follows WIT rule but fails to arise when the central bank follows the Ramsey policy. In particular, a considerable boom in the durable good sector occurs under the WIT rule while a slight bust in the durable sector occurs under the Ramsey policy. The underlying mechanism is as follows: recall non-durable goods and durable goods are assumed to be substitutes in this case; agents would rather postpone their accumulation of durable goods since they can be easily replaced by non-durable goods once the expected technology improvement is realized. However, a WIT rule causes a relatively lower real interest rate in durable sector and a lower user cost, which spurs agents’ incentive to accumulate durable goods.

Figure 6 shows that a little difference in the real interest rate can cause a great difference in user cost. When agents expect the technology in the non-durable sector will improve in the future, they also expect that the relative price of durable goods will rise, that is, a chance to capture the capital gain. A relative higher real interest rate under the Ramsey
policy dampens the discounted present value of the capital gain and depresses the agents’ incentives to capture the capital gain. By contrast, a relative lower real interest rate under WIT rule gives the agents more incentives to capture the expected capital gain by accumulating durable goods. The conclusion is that monetary policy has a significant effect on the generation of Pigou cycles by affecting the real interest rate and user cost of durable goods. The assumption of a strong complementarity between non-durable goods and durable goods is not necessary any more to generate Pigou cycles when the monetary policy rule employed by central bank fails to raise the real interest rate enough to dampen the desire to capture the capital gain.

5. Conclusion

In this paper, I explored the expectation driven business cycles (Pigou cycles) and optimal monetary policy in a two-sector economy with nominal rigidities in both non-durable goods and durable goods sectors. My main findings are as follows: (1) nominal rigidities tend to magnify the extent of the boom and bust when a news shock hits the economy and no active monetary policy is employed; (2) The Ramsey optimal policy requires the central bank to raise the nominal interest rate before the realization of the news, so that the real interest rate and user cost of durable goods are raised to dampen the agents’ incentive to accumulate durable goods; (3) The Ramsey optimal policy succeeds in restoring the total labor supply to its flexible price level but fails to do so for the output of non-durable goods and durable goods. (4) The Ramsey optimal policy is closely mimicked by a simple policy rule targeting inflations in both durable and non-durable
sectors. More weight should be given to the durable good sector unless the degree of nominal rigidity in the durable good sector is much smaller than that in the non-durable good sector.

Monetary policy also plays an important role in generating Pigou cycles by altering the real interest rate. A rise in the real interest rate reduces the present value of the capital gain and increases the user cost, which causes a decline in durable goods accumulation. When agents receive a signal indicating a technology improvement in the non-durable sector, they expect that the relative price of durable goods will increase and a capital gain can be captured. The reaction of a central bank following the Ramsey optimal policy is to raise the real interest rate which has the effect of reducing the present value of the capital gain and prevent the agents from accumulating too much durable goods. If the central bank does not raise the real interest rate enough, a high expected capital gain stimulates the accumulation of durable goods. Under such a circumstance, Pigou cycles can arise without the assumption of a strong complementarity between non-durable goods and durable goods.

In this paper, the coefficients of simple policy rules are estimated using the simulated interest rates under the Ramsey optimal policy. The fit is measured simply by R-square or visual closeness of the IRFs. A possible extension is to define an appropriate measurement of welfare and calculate the welfare loss for alternative implementable simple rules relative to the welfare under the Ramsey optimal policy.
## Appendix:

### Table 2: Baseline Parameter Values

<table>
<thead>
<tr>
<th>$\beta$</th>
<th>$\alpha$</th>
<th>$\delta$</th>
<th>$\eta$</th>
<th>$\nu$</th>
<th>$\varepsilon_d$</th>
<th>$\varepsilon_c$</th>
<th>$\omega_c$</th>
<th>$\omega_d$</th>
<th>$\rho_c$</th>
<th>$\rho_d$</th>
<th>$\sigma_z$</th>
<th>$\sigma_{\xi}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.99</td>
<td>0.87</td>
<td>0.025</td>
<td>0.2</td>
<td>0.80</td>
<td>8</td>
<td>8</td>
<td>0.75</td>
<td>0.75</td>
<td>0.95</td>
<td>0.95</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Figure 1
Responses to news at period 1 of future positive shock on the technology in non-durable sector and no realization of that shock at period 5 (line with circles: exogenous money supply, line with stars: Ramsey optimal policy, solid line: flexible prices). All parameters are in baseline values.

Figure 2
Responses to news at period 1 of future positive shock on the technology in non-durable sector and realization of that shock at period 5 (line with circles: exogenous money supply, line with stars: Ramsey optimal policy, solid line: flexible prices). All parameters are in baseline values.
Figure 3
Responses to news at period 1 of future positive shock on the technology in non-durable sector and no realization of that shock at period 5 (line with circles: exogenous money supply, line with stars: Ramsey optimal policy, solid line: flexible prices)

Elasticity of substitution between non-durable and durable $\eta = 0.9999$.

Figure 4
Responses to news at period 1 of future positive shock on the technology in durable sector and no realization of that shock at period 5 (line with circles: exogenous money supply, line with stars: Ramsey optimal policy, solid line: flexible prices)
Figure 5

Responses to news at period 1 of future positive shock on the technology in non-durable sector and no realization of that shock at period 5 (line with circles: estimated simple interest rule, line with stars: Ramsey optimal policy).

Simple interest rule: $R_i = 4.036 + 1.222 \pi_i - 0.013 x_i$
Figure 6 (Asymmetric nominal rigidity)
Responses to news at period 1 of future positive shock on the technology in non-durable sector and no realization of that shock at period 5 (line with circles: estimated simple interest rule, line with stars: Ramsey optimal policy).

Simple interest rule: \( R_t = R^r + \beta'_1 \pi_{c,t} + \beta'_2 \pi_{d,t} \)  
\( (\beta'_1 = 2.219; \beta'_2 = 0.887; \eta = 0.2; \varepsilon_c = 0.75; \varepsilon_d = 0.4) \)

Simple interest rule: \( R_t = R^r + \beta'_1 \pi_{c,t} + \beta'_2 \pi_{d,t} \)  
\( (\beta'_1 = 11.78; \beta'_2 = 0.83; \eta = 0.2; \varepsilon_c = 0.75; \varepsilon_d = 0.25) \)
Figure 7
Responses to news at period 1 of future positive shock on the technology in non-durable sector and no realization of that shock at period 5 (lines with stars: Ramsey policy, lines with circles: simple policy rule weakly targeting inflation).
Elasticity of substitution between non-durable and durable $\eta = 2$. 

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**Graphs:**
- Non-durable goods consumption ($c$)
- Durable goods stock ($d$)
- Durable goods production ($i$)
- Combination of $c$ and $d$
- Total labor supply
- Labor supply in non-durable sector
- Labor supply in durable sector
- Relative price
- Nominal interest rate
- Real interest rate non-durable
- Real interest rate durable
- User cost

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References


