A New Cost Channel of Monetary Policy*

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Abstract

In this paper, I developed a *new cost channel* of monetary policy transmission in a small scale, dynamic, general equilibrium model. The new cost channel of monetary policy transmission implies that the frequency of price adjustment increases in the nominal interest rate. I found that allowing for the new cost channel can account both for the muted and delayed inflation response and for the persistence of the output response to monetary policy shocks. Without any additional assumption, my model can also generate the delayed output response, though for a slightly more competitive goods market calibration.

JEL classification: E31; E32; E52.

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1 Introduction

Understanding the dynamics of output and inflation in the aftermath of a monetary policy shock is a key issue in macroeconomic research. Developing a deeper understanding of this issue requires a detailed analysis of the link between inflation and price adjustment by firms. The analysis of this link calls for a careful study of why firms adjust prices sluggishly.

Rigorous attempts to explaine the sluggishness of prices are the theories of (i) imperfect information (Phelps 1970, Lucas 1972, Mankiw and Reis 2002), (ii) costly price adjustment and menu costs (Rotemberg 1982, Mankiw 1985, Akerlof and Yellen 1985), and (iii) costly information (Ball and Mankiw 1994). The theories developed by Taylor (1980), Rotemberg (1982), and Calvo (1983) have been widely applied in recent research as devices for modeling sticky prices in dynamic, general equilibrium frameworks.

These widely used theories of sluggish price adjustment cannot explain two stylized facts that have been documented by empirical researchers. First, Fabiani et al. (2005) report that implicit contracts between firms and their customers appear to be the main explanation of price stickiness in the euro area. Menu costs and costly information are found to be of minor importance. Implicit contracts imply that firms and their customers have long-term relations, and in order not to antagonize their customers firms reset prices only after cost shocks, but not after demand shocks.[1]

Second, the theories of Taylor (1980), Rotemberg (1982), and Calvo (1983) imply a time-dependent pricing policy which, in turn, implies that the frequency of price adjustment is constant. Apel et al. (2005) and Fabiani et al. (2005), however, report that macroeconomic conditions affect the frequency of price adjustment. The view that the frequency of price adjustment should be taken as endogenous has also been suggested by Konieczny and Skrzypacz (2006) who report evidence that the intensity of consumer search for the best price affects the frequency of price adjustment.

In order to account for these two stylized facts, I analyze the effects of monetary

[1] For studies yielding similar results, see Blinder et al. (1998) for the US, Hall et al. (2000) for the UK, Amirault et al. (2004) for Canada, and Apel et al. (2005) for Sweden.

policy on output and inflation in an extension of a model developed by Rotemberg (2005). Rotemberg's model is based upon behavioral economics, and it captures the connotations of both implicit contract theory and a variable frequency of price adjustment. Another appealing feature of Rotemberg's model is that it generalizes to positive long-run trend inflation, which is in line with economic data of industrial countries.

Rotemberg (2005) assumes that price increases are viewed by costumers as fair and justifiable only if these increases are triggered by cost increases. Otherwise customers get upset, and the relationship between the firm and its customers breaks down.[2] Consumers have imperfect information about the cost of firms, but they receive random signals about costs. In Rotemberg's (2005) model, relative prices and inflation are signals about the fairness of price increases, and, in particular, inflation is a signal of cost increases. For this reason, the probability that firms can reset its price is a function of relative and general price level increases.

My extension of Rotemberg's (2005) model is motivated by the recent studies on the so-called cost channel of monetary policy transmission (See, for example, Barth and Ramey 2001, Ravenna and Walsh 2006, Chowdhury et al. 2006, and Gaiotti and Secchi 2006). These studies present empirical evidence of the presence of the cost channel. The cost channel implies that, apart from affecting the *demand* side of the economy, monetary policy shocks affect also the *supply* side because they affect firms' cost of financing working capital.

Building on the research on the cost channel of monetary policy, in my model, consumers perceive contractionary monetary changes as cost increases. Because consumers have imperfect information about the cost of firms, the interest rate is an easily-available, easy-to-monitor signal of cost-push shocks. Moreover, the interest rate contains important information about the overall state of the economy, which, in turn, is important because, as suggested by Rotemberg (2005), "*the frequency of price adjustment can depend on economy-wide variables observed by consumers*". Because the cost channel of monetary

[2]This assumption, first suggested by Okun (1981), is consistent with the survey evidences, and it is also in line with the recent experimental study of Renner and Tyran (2004).

policy I develop in this paper differs from the traditional cost channel discussed in the earlier literature, I will henceforth call it *the new cost channel.* I will use the term *the working capital cost channel* when I refer the traditional cost channel.

Using a small-scale, dynamic, New Keynesian, general equilibrium model, I show that the new cost channel has substantial implications for the propagation of monetary policy shocks. The responses of inflation and output to monetary policy shocks are more realistic in my model featuring the new cost channel than in the model featuring only the working capital cost channel. The response of inflation in my model is delayed and persistent. My model also implies a significant increase in the persistence of the effect of monetary policy shocks on output. Further, my model implies an increase in the persistence of the response of the nominal interest rate. Importantly, these results also obtain when the working capital cost channel is absent from my model.

I organize the remainder of my paper as follows. In Section 2, I lay out the dynamic, general equilibrium model I used to derive my results. In Section 3, I report the results of numerical simulations. In Section 4, I report the results of sensitivity analyses. In section 5, I conclude.

2 The Model Economy

The economy operates in discrete time, and monetary policy is the only source of uncertainty. The economy consists of households, firms, a financial intermediary, and a monetary authority. The numbers of households and firms are assumed to be large. For tractability, I assume a continuum of households, indexed by j, and firms, indexed by z, with $j, z \in [0, 1]$.

2.1 Households

The expected present value of lifetime utility of a representative household j is given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t^j)^{1-\sigma^{-1}} - 1}{1 - \sigma^{-1}} - \frac{(N_t^j)^{1+\phi}}{1+\phi} \right], \tag{1}$$

with

$$C_t^j \equiv \left[\int_0^1 c_t^j(z)^{\frac{\theta-1}{\theta}} \mathrm{d}z \right]^{\frac{\theta}{\theta-1}}, \tag{2}$$

where $0 < \beta < 1$ is the discount factor, $0 < \sigma$ is the intertemporal elasticity of substitution, $0 < \phi$ is the inverse of the elasticity of labor supply with respect to real wages, and $1 < \theta$ is the elasticity of substitution among differentiated goods. E_t is the mathematical expectation operator conditional on period t information, N_t^j is the quantity of labor supplied by household j, and $c_t^j(z)$ denotes household j's consumption of good z. Using the Dixit Stiglitz (1977) aggregator given in (2), I derived the corresponding price index, P_t, defined as the price of one unit of the composite consumption good, C_t:

$$P_t = \Big[\int_0^1 P_t(z)^{1-\theta} \mathrm{d}z \Big]^{\frac{1}{1-\theta}}. \tag{3}$$

The demand of household j for good z is given by

$$c_t^j(z) = \left[\frac{P_t(z)}{P_t} \right]^{-\theta} C_t^j, \tag{4}$$

where $P_t(z)$ is the price of good z.

In order to maximize its utility function given in (1), the household j chooses C_t^j, N_t^j, and the amount of nominal riskless one-period bonds B_t^j to carry over to the next period. The period-t budget constraint is

$$R_t^{-1} B_t^j + P_t C_t^j \leq B_{t-1}^j + P_t \Pi_t^j + W_t N_t^j, \tag{5}$$

where R_t is the gross nominal returns on bond holdings, W_t is the nominal wage rate determined in a competitive labor market, and Π_t^j is the sum of the household's profit income received from the financial intermediary and firms. Each household holds the same amount of shares of the financial intermediary and the same amount of shares of each firm.

The optimality conditions for the household's maximization problem are given by a no-arbitrage argument

$$1 = E_t \left(\prod_{s=0}^{i} R_{t+s} \right) E_t \Lambda_{t,t+i} \quad i = 1, 2, \ldots, \tag{6}$$

where $\Lambda_{t,t+i}$ is the stochastic discount factor for nominal payoffs and defined as

$$\Lambda_{t,t+i} \equiv \beta^i \left(\frac{C^j_{t+i}}{C^j_t} \right)^{-\sigma^{-1}} \frac{P_t}{P_{t+i}}, \tag{7}$$

the labor supply equation

$$\frac{(N^j_t)^\phi}{(C^j_t)^{-\sigma^{-1}}} = \frac{W_t}{P_t}, \tag{8}$$

a solvency condition, and the binding version of the budget constraint given in (5).

2.2 Firms

Each firm operates in a monopolistically competitive goods market. The demand curve is given by

$$y_t(z) = \left[\frac{P_t(z)}{P_t} \right]^{-\theta} C_t, \tag{9}$$

where $y_t(z)$ is the good produced by firm z and $C_t \equiv \int_0^1 C^j_t \mathrm{d}j$ is total consumption.

The production function is given by

$$y_t(z) = N_t(z), \tag{10}$$

where $N_t(z)$ is the labor input of firm z.

To model the working capital cost channel, I assume that the workers are paid before production takes place. Therefore, at the beginning of period t, each firm has to borrow an amount of $W_t N_t(z)$ from the financial intermediary to finance its wage bill, and at the end of the period this amount has to be paid back with an interest of $R_t - 1$. Given the production function in (10), and the cost structure of the firm, cost minimization requires

$$mc_t = R_t w_t, \tag{11}$$

where mc_t is the real marginal costs and $w_t \equiv W_t/P_t$.

To model price stickiness, I use the price setting mechanism developed by Rotemberg (2005). The distinguishing feature of the setting suggested by Rotemberg is that the probability that a firm can reset its price, is variable and endogenous rather than constant and exogenous. Firms can change the price in every period with probability $0 < 1-\alpha_t < 1$.

Leaving a more detailed discussion of the properties of α_t aside for the moment, the maximization problem of a typical firm can be expressed as

$$\max_{P_t(z)} E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left(\prod_{l=1}^{i} \alpha_{t+l} \right) y_{t+i}(z) \left[P_t(z) - P_{t+i} mc_{t+i} \right], \tag{12}$$

subject to

$$y_t(z) = \left[\frac{P_t(z)}{P_t} \right]^{-\theta} C_t,$$

where I invoke the condition $\prod_{l=1}^{0} \alpha_{t+l} \equiv 1$. Firms set the price so as to maximize the expected present discounted value of profits. Using the demand curve to substitute for $y_t(z)$ in (12) and maximizing it over $P_t(z)$ gives

$$E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left(\prod_{l=1}^{i} \alpha_{t+l} \right) y_{t+i}(z) \left[P_t(z) - \frac{\theta}{\theta - 1} P_{t+i} mc_{t+i} \right] = 0. \tag{13}$$

Denote the relative price, $P_t(z)/P_t$, as X_t and the gross inflation rate, P_t/P_{t-1}, as π_t. Using (13), X_t can be expressed as

$$X_t = \frac{\theta}{\theta - 1} \frac{E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left(\prod_{l=1}^{i} \alpha_{t+l} (\pi_{t+l})^{1+\theta} \right) C_{t+i} mc_{t+i}}{E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left(\prod_{l=1}^{i} \alpha_{t+l} (\pi_{t+l})^{\theta} \right) C_{t+i}}. \tag{14}$$

Because I assume symmetry across firms, implying that the firms that can reset their prices choose the same new price, I denote the relative price by X_t rather than by $X_t(z)$. The price index (3), therefore, can be written as

$$P_t = \left(\alpha_t (P_{t-1})^{1-\theta} + (1 - \alpha_t)(P_t(z))^{1-\theta} \right)^{1/1-\theta},$$

which implies

$$\alpha_t (\pi_t)^{\theta - 1} + (1 - \alpha_t)(X_t)^{1-\theta} = 1. \tag{15}$$

2.3 The Financial Intermediary

The financial intermediary operates costlessly, borrows an amount of M_t from the monetary authority at the rate $R_t - 1$, and lends the amount $W_t \int_0^1 N_t(z) \mathrm{d}z$ to the firms at the rate $R_t - 1$. This implies that the profit of the financial intermediary is zero. I assume the monetary authority transfers its interest income $W_t \int_0^1 N_t(z) \mathrm{d}z (R_t - 1)$ to the financial intermediary which in turn distributes it to its shareholders.

2.4 Aggregation

Because I study a symmetric equilibrium, I can drop the indices of j's and z's from all equations but equation (9). The reason for excluding equation (9) is that the so-called *inefficient price dispersion*, an issue first pointed out by Schmitt-Grohé and Uribe (2004). To view this issue, integrate both sides of the equation (9) over z. The result is the resource constraint

$$Y_t = s_t C_t,$$

where $Y_t \equiv \int_0^1 y_t(z)\mathrm{d}z$, and $s_t \equiv \int_0^1 \left(\frac{P_t(z)}{P_t}\right)^{-\theta} \mathrm{d}z$. Because s_t is bounded below by 1 as shown by Schmitt-Grohé and Uribe (2004), aggregate production may differ from aggregate consumption. Thus the price dispersion generated by the assumed price setting mechanism is a costly distortion. Applying the same reasoning used to derive equation (15), s_t can be expressed as

$$s_t = (1-\alpha_t)X_t^{-\theta} + \alpha_t \pi_t^{\theta} s_{t-1}. \tag{16}$$

The market clearing conditions for the markets of bonds, labor, and loans are given by

$$\int_0^1 B_t^j \mathrm{d}j = 0, \quad (N_t \equiv) \int_0^1 N_t(z)\mathrm{d}z = \int_0^1 N_t^j \mathrm{d}j, \quad \text{and } M_t = W_t N_t.$$

2.5 The Frequency of Price Adjustment

As the assumption of a variable frequency of price adjustment is a key feature of my model, it deserves special attention. As is widely known, models employing the price setting mechanism of Calvo (1983) assume that in any period of time a constant fraction of randomly selected firms cannot change their prices. This implies a constant time path for the frequency of price adjustment. Because of this constant frequency, models employing the Calvo (1983) type price setting mechanism suffer from Lucas (1976) critique.[3] The recent study of Konieczny and Skrzypacz (2006) provides empirical evidence that contradicts the constant frequency of price adjustment. Also, the results of recent survey studies

[3] Moreover, Calvo (1983) mechanism gives rise to counterfactual results in the presence of positive trend inflation (Bakhshi et al. 2003).

by Abel et al. (2005) and by Fabiani et al. (2005) suggest that the frequency of price adjustment is affected by macroeconomic conditions.

By building on the theory of implicit contracts, Rotemberg (2005) generalizes Calvo's (1983) model to incorporate a variable and endogenous frequency of price adjustment. The theory of implicit contracts implies that firms are reluctant to change prices because they have some sort of long term relationships with their customers, who do not like price increases. After an increase of the price of a firm, the relationship of the firm with its customers breaks down unless the customers believe that the increase in the price was triggered by cost increases, and, thus, fair.

Following Rotemberg (2005), I assume that the relative price, X_t, and the inflation rate in the last period, π_{t-1}, are signals about the perceived fairness of price increases, and, in particular, π_{t-1} is a signal of cost increases. Because, ceteris paribus, an increase in the relative price will imply that the absolute price is increased more relative to other prices, X_t is a 'negative' signal of fairness. Because inflation implies an overall increase in costs, π_{t-1} is a 'positive' signal of fairness. In addition to X_t and π_{t-1}, which are the variables affecting the frequency of price adjustment in Rotemberg (2005), I assume that the nominal interest rate, R_t, is also such a signal because consumers perceive nominal interest changes as cost changes. This assumption can be justified by considering that an increase in the nominal interest rate negatively affects the firm's cost of financing working capital. Because of this cost-push effect, the increase in the nominal interest rate can be pointed to consumers as an increase in costs, i.e., R_t is a 'positive' signal of fairness. Moreover, as a signal of changes in costs, the nominal interest rate is easily available and easy to monitor. Consequently, as the nominal interest rate contains important information about the overall state of the economy, the nominal interest rate act as a proxy for cost-change-signalling variables that are absent in the model.

Accordingly, firms adjust their prices only when they believe that the price increase will not bring about a customer resistance, i.e., a sharp fall in demand.[4] Thus, the random

[4] Price decreases, on the other hand, are excluded from the analysis by assuming that the steady state level of inflation is sufficiently large which, in turn, makes the price decreases nonoptimal.

signals that govern the fairness evaluation of a price increase also govern the probability of the price adjustment:

$$\tilde{\alpha}_t = \gamma_x \tilde{X}_t + \gamma_\pi \tilde{\pi}_{t-1} + \gamma_R \tilde{R}_t, \tag{17}$$

where a variable with a tilde denotes the logarithmic deviation from steady state level. As regards the signs of the parameters, γ_x is positive since, ceteris paribus, an increase in the relative price will decrease the reset probability, $1 - \tilde{\alpha}_t$. As higher inflation will imply more frequent price adjustments, γ_π is negative, so that the reset probability rises with higher inflation.[5] Finally, the parameter γ_R is negative because of the cost-push effect of nominal interest rate increases.

2.6 Log-linearized Equilibrium Conditions

I log-linearized the equations of the model around a positive level of steady-state inflation. In my model, as in Rotemberg's (2005) model, invoking the assumption of trend inflation is a necessary condition for the variations in the frequency of price adjustments to have an effect on the propagation of monetary policy shocks. Besides confirmed by economic data, trend inflation has important implications for the transmission of monetary policy shocks, as shown, for example, in Ascari (2004) and Kiley (2004).

In addition to equation (17), the other log-linearized equations used to analyze the effects of monetary policy are given by

$$\textit{aggregate consumption euler equation:} \quad \tilde{C}_t = E_t \tilde{C}_{t+1} - \sigma(\tilde{R}_t - E_t \tilde{\pi}_{t+1}), \tag{18}$$

$$\textit{labor supply:} \quad \phi \tilde{N}_t + \frac{1}{\sigma} \tilde{C}_t = \tilde{w}_t, \tag{19}$$

$$\textit{real marginal costs:} \quad \tilde{mc}_t = \tilde{w}_t + \tilde{R}_t, \tag{20}$$

$$\textit{resource constraint:} \quad \tilde{Y}_t = \tilde{N}_t = \tilde{s}_t + \tilde{C}_t, \tag{21}$$

$$\textit{price dispersion:} \quad \tilde{s}_t = \theta(\alpha\pi^\theta - 1)\tilde{X}_t + \frac{\alpha(\pi^\theta - 1)}{1-\alpha}\tilde{\alpha}_t + \theta\alpha\pi^\theta \tilde{\pi}_t + \alpha\pi^\theta \tilde{s}_{t-1}, \tag{22}$$

$$\textit{inflation:} \quad \tilde{\pi}_t = (\alpha^{-1}\pi^{1-\theta} - 1)\tilde{X}_t + \frac{\pi^{1-\theta} - 1}{(1-\alpha)(\theta-1)}\tilde{\alpha}_t, \tag{23}$$

[5] This idea is emphasized also in Bakhshi et al. (2003).

$$\textit{optimal price:} \quad \tilde{X}_t = \varphi_\pi \tilde{\pi}_t + \varphi_{mc} \tilde{mc}_t + \varphi_c \tilde{C}_t + \varphi_\alpha \tilde{\alpha}_t, \tag{24}$$

where

$$\varphi_\pi \equiv \lambda_2 L^{-1}\big[(\pi-1)\theta + 1 - \lambda_1 L^{-1}\big]\,\big[\big(1-\lambda_1 L^{-1}\big)\,\big(1-\lambda_2 L^{-1}\big)\,\big]^{-1},$$

$$\varphi_{mc} \equiv \big(1-\lambda_1\big)\big(1-\lambda_1 L^{-1}\big)^{-1},$$

$$\varphi_c \equiv \big[\lambda_2\,(1-\pi)\,\big(1-\sigma^{-1}\big)\,\big(1-L^{-1}\big)\,\big]\,\big[\big(1-\lambda_1 L^{-1}\big)\,\big(1-\lambda_2 L^{-1}\big)\,\big]^{-1},$$

$$\varphi_\alpha \equiv \big[\lambda_2(1-\pi)L^{-1}\big]\big[\,\big(1-\lambda_1 L^{-1}\big)\,\big(1-\lambda_2 L^{-1}\big)\,\big]^{-1}.$$

where $\lambda_1 \equiv \alpha\beta\pi^{\theta}$, $\lambda_2 \equiv \alpha\beta\pi^{\theta-1}$, and L denotes the lag operator.[6,7] Note that if steady state inflation is zero, $\pi = 1$, the coefficients of $\tilde{\alpha}_t$ are zero in equations (22), (23), and (24), i.e., variations of α_t do not affect any variable in the model. Equations (17) and (23) constitute the Phillips-curve block of the model.

In order to close the model, I assume that the monetary authority conducts its policy according to a reaction function given by

$$\tilde{R}_t = \rho_\pi \tilde{\pi}_t + \rho_L \tilde{R}_{t-1} + \varepsilon_t^R, \tag{25}$$

where ε_t^R is the unanticipated shock to monetary policy, and is assumed to be white-noise.

2.7 Calibration and Solution of the Model

I calibrate the parameters of my model as summarized in panel A of Table 1. In order to visualize the effects of varying parameter values, I will conduct sensitivity analyses in next section. The intervals for these parameters are summarized in panel B of Table 1.

— Insert Table 1 about here. —

[6]Without using the lag operators, equation (24) can be expressed as

$$\begin{aligned}\tilde{X}_t = E_t[&(\lambda_1+\lambda_2)\tilde{X}_{t+1} - (\lambda_1\lambda_2)\tilde{X}_{t+2} + (\theta(\lambda_1-\lambda_2)+\lambda_2)\,\tilde{\pi}_{t+1} - (\lambda_1\lambda_2)\tilde{\pi}_{t+2} + (1-\lambda_1)\tilde{mc}_t \\ &-\lambda_2(1-\lambda_1)\tilde{mc}_{t+1} + (\lambda_2-\lambda_1)(1-\sigma^{-1})\tilde{C}_t + (\lambda_1-\lambda_2)(1-\sigma^{-1})\tilde{C}_{t+1} + (\lambda_1-\lambda_2)\tilde{\alpha}_{t+1}].\end{aligned}$$

[7]Using equations (17) and (24) to substitute for $\tilde{X}_t$, equation (23) can be expressed as

$$\begin{aligned}\tilde{\pi}_t = E_t[&((\beta-\lambda_2)(\pi-1)\theta+\beta+\lambda_1)\tilde{\pi}_{t+1} - \beta\lambda_1\tilde{\pi}_{t+2} + (\beta-\lambda_2)(1-\lambda_1)\lambda_2^{-1}\tilde{mc}_t \\ &-(\beta-\lambda_2)(1-\lambda_1)\tilde{mc}_{t+1} + (\beta-\lambda_2)(1-\pi)(1-\sigma^{-1})\tilde{C}_t - (\beta-\lambda_2)(1-\pi)(1-\sigma^{-1})\tilde{C}_{t+1} \\ &+\lambda_3\alpha_t + ((\beta-\lambda_2)(1-\pi) - (\lambda_1+\lambda_2)\lambda_3)\tilde{\alpha}_{t+1} + \lambda_1\lambda_2\lambda_3\tilde{\alpha}_{t+2}],\end{aligned}$$

where $\lambda_3 \equiv \frac{(\pi^{1-\theta}-1)}{(1-\alpha)(\theta-1)}$.

The calibration of the parameters characterizing preferences is based on Ravenna and Walsh (2006), and is standard in the literature. Setting one period to equal a quarter of a year, I set the discount factor $\beta = 1.041^{-1/4}$ so that the annual rate of interest is 4.1%. I set $\sigma^{-1} = 1.5$ implying a higher risk aversion than logarithmic utility. I set the inverse of the labor supply elasticity, ϕ, to 1. I set $\theta = 11$, implying a markup rate of 10%.

The parameters characterizing the price adjustment mechanism are calibrated following Rotemberg (2005). I set π equal to $1.05^{1/4}$, so that the annual inflation is 5%, and X equal to 1.05. When steady state inflation is zero, steady state values of X_t and s_t are equal to 1 irrespective of the steady state value of α_t. Given the values of θ, π and X, equation (15) implies $\alpha = 0.7485$ which, in turn, indicates that, on average, firms adjust their prices once a year. I set $\gamma_x = 2.5$ and $\gamma_\pi = -15$. I set the parameter γ_R, governing the effect of the new cost channel, equal to -10.

For the parameter values of the monetary authority's reaction function, I set $\rho_\pi = 0.9$ and $\rho_L = 0.9$. These two values are based on Rotemberg (2005).

Finally, the algorithm developed by Klein (2000) and McCallum (2001) is used to solve and simulate the model.

3 Effects of Monetary Policy Shocks

3.1 A Comparison of Four Alternative Models

Before analyzing the effects of monetary policy shocks in my model, it will be convenient to highlight the implications of the working capital cost channel and the variable frequency of price adjustment for the propagation of monetary policy shocks. To this end, I consider four distinct versions of my model. The first one is a standard New Keynesian model, the structure of which is equivalent to that of the model of Section 2, except that it features Calvo (1983) type price staggering and no working capital cost channel. The second one extends the first one to allow the working capital cost channel. The third one replaces Calvo-type price staggering in the first one with Rotemberg's (2005) pricing. And the fourth one extends the third one to allow the working capital cost channel. In the last two models, I considered the pure Rotemberg setting, and thus, abstracted from the new cost channel, the implications of which I shall present in Section 3.2. All four models considered feature trend inflation.

Figure 1 presents the impulse response functions for the four distinct models. The impulse response functions describe the dynamics of four variables −output, inflation, α_t, and the nominal interest rate− in the aftermath of a one percentage point positive shock to the nominal interest rate. Comparing the impulse response functions for Models 1 and 3 and Models 2 and 4 highlights the role played by the working capital cost channel on the dynamics of inflation and output in the aftermath of contractionary monetary policy shock. The impulse response functions illustrate the result that the working capital cost channel do not significantly affect the responses of output, inflation, α_t, and nominal interest rate. Furthermore, this result obtains irrespective of Calvo or Rotemberg type price setting mechanism. For example, the difference in the initial output responses in the first two models −featuring Calvo pricing − is 0.0820, whereas the corresponding statistic in the latter two models −featuring Rotemberg pricing− is 0.0858. Thus, the working capital cost channel does not play a critical role for the dynamics of output and inflation, a result also emphasized by Christiano, Eichenbaum and Evans (2005).

— Insert Figure 1 about here. —

As regards the role of the variable frequency of price adjustment for the propagation of monetary policy shocks, my results are qualitatively similar to those of Rotemberg (2005). Comparing the impulse response functions for Models 1 and 2 and Models 3 and 4 shows that Rotemberg-type pricing produces a delayed response of inflation as shown in the data (Christiano, Eichenbaum and Evans 1999). Since the impact of a shock on inflation in the models with Rotemberg pricing are less than those in the models with Calvo pricing, the impact on output is greater in the models with Rotemberg pricing.

3.2 Implications of the New Cost Channel

Figure 2 depicts impulse response functions for the model of Section 2 −the baseline model− and for Rotemberg's (2005) model. Note that the difference between the baseline model and Rotemberg model is that the former extents the latter by introducing the new cost channel. As can be seen from Figure 2, this extension significantly alters the dynamics of model variables.[8]

— Insert Figure 2 about here. —

The response of inflation generated by the baseline model (solid line) is more delayed and more persistent than the inflation response generated by the Rotemberg model (dot-dashed line). The baseline model generates also less volatile inflation. The reason for this is that allowing for the new cost channel causes a significant downward shift in the response of α_t. This arises because the coefficient of α_t in equation (23) is always negative due to $\pi, \theta > 1$. A larger response of α_t, in turn, implies a muted response of inflation even though the response of relative prices also shifts downwards in my model (not shown in Figure 2).[9] In short, the stronger the (negative) response of α_t the weaker the (negative) response of inflation. The muted response of inflation, in turn, gives rise to a higher increase in the real interest rate through two channels. The first channel is the well known Fisher condition: $\tilde{r}_t = \tilde{R}_t - \tilde{\pi}_{t+1}$, where $\tilde{r}_t$ denotes the real interest rate. The second channel is the reaction function of the monetary authority, $\tilde{R}_t = 0.9\tilde{\pi}_t + 0.9\tilde{R}_{t-1}$. Thus, the reduced and stretched inflation response increases the response of the real interest rate directly through the Fisher condition and indirectly through the reaction function of the monetary authority. This indirect effect explains in part the magnified responses of α_t and price dispersion.

The increased response of real interest rate implies because of the Euler equation a more persistent consumption and output effects. But comparing the consumption and output responses for the two models highlights that accounting for price dispersion has nontrivial consequences only in the extended model. The assumption of the new cost channel implies a significant increase in the response of output with respect to that of consumption due to the increase in the response of the price dispersion.

[8] Note that both models feature the working capital cost channel. The results do not change if I remove the working capital cost channel from the models because, as shown in Section 3.1, it does not play a significant role for the dynamics of the model.

[9] The decrease in relative price falls short of the decrease in α_t.

To illustrate further the implications of the assumption of the new cost channel, I assumed $\gamma_R = -13$ and $\theta = 15$, and simulated the effects of a monetary tightening for this particular case as well as for the benchmark case. Figure 3 depicts the impulse response functions for both this specific calibration (solid line) and the benchmark calibration, $\gamma_R = -10$, $\theta = 11$, (dot-dashed line). Note that setting $\theta = 15$ implies a more competitive goods market and a steady state level of 0.7266 for α_t. A more competitive goods market and a greater γ_R (in absolute value) shift the response of output downwards, and generate a hump-shaped output response. As regards inflation, its response is reduced, and the delay of the peak of the inflation response is now six quarters, whereas for the benchmark calibration it is four quarters. By switching from the benchmark calibration to the new one, neither the consumption response nor the inflation response are altered significantly.

— Insert Figure 3 about here. —

In sum, my results suggest that accounting for the new cost channel can generate empirically realistic output and inflation responses to monetary policy shocks.

4 Sensitivity Analyses

I now analyze the sensitivity of my results to various changes in the calibration of the parameters π, γ_x, γ_π, γ_R, σ, ϕ and θ. Note that any variation in the steady-state of inflation implies a variation in the steady-state of α_t. Thus, by analyzing the sensitivity of my results with respect to the steady state inflation, I implicitly analyze the sensitivity of my results with respect to the degree of price stickiness as well.

In order to summarize the results of the sensitivity analyses, I use three dimensional graphs. The graphs illustrate how the variation in a parameter alters the impulse response functions. The alternative values of the parameter in question are shown on the northwest-southeast axis of the graphs.

Figure 4 displays the responses of output and inflation for $\pi \in [1.05^{1/4}, 1.50^{1/4}]$ (first row), $\gamma_x \in [0, 3]$ (second row), $\gamma_\pi \in [-25, 0]$ (third row), and $\gamma_R \in [-20, 0]$ (last row). Given $X = 1.05$ and $\theta = 11$, a 5% annual inflation implies $\alpha = 0.7485$, whereas a 50%

annual inflation implies $\alpha = 0.1803$. The graphs in the first row shows that the response of inflation shifts downwards with the increase in π, which, in turn, decreases the persistence of the output response. This implies that the Phillips-curve gets steeper with the increase in steady-state inflation. Moreover, the delay of the peak of the inflation response decreases from 4 quarters to 1 quarter when π increases from $1.05^{1/4}$ to $1.50^{1/4}$. In other words, the delay is 4 quarters when prices are, on average, reset every 4 quarters, and the delay is 1 quarter when prices are, on average, reset every quarter. The second row graphs 4 shows that the increase in γ_x brings about a stronger output response and a more muted inflation response. The third row graphs shows that the results are robust to the choice of γ_π, and illustrates that $\gamma_\pi > 0$ is necessary for a delayed peak in inflation response. The graphs in the last row confirm the results of Section 3.2. As the response of inflation magnifies, the persistence of the output response decreases with the decrease in γ_R.

— Insert Figure 4 about here. —

Figure 5 presents results of the sensitivity analyses with regard to the preference parameters. Variations in the parameters do not alter the patterns of the responses significantly except for those expected. The volatility of output increases with the decrease in the coefficient of relative risk aversion, σ^{-1} as shown by the graphs in the first row. The graphs in the last row replicates the result of Section 3.2 that a more competitive goods market increases the output response because of the increase in the response of the price dispersion. A change in the competitiveness of the goods market induced by the variation in the elasticity of substitution, θ, does not affect the response of consumption (not shown in Figure 5). Thus, the results of Section 3.2 are robust with respect to the calibration of preferences.

— Insert Figure 5 about here. —

5 Conclusions

I incorporated the cost channel of monetary policy, the variable frequency of price adjustment, and trend inflation into a small scale, dynamic, general equilibrium model. First, I found that allowing for the working capital cost channel does not significantly alter output and inflation effects of monetary policy shocks, as has also been emphasized by Christiano et al. (2005). Second, I showed that assuming the new cost channel, which implies that the frequency of price adjustment increases in the nominal interest rate, can account both for the persistence of the output response and for the muted and delayed inflation response to monetary policy shocks found in several VAR studies (e.g. Christiano et al. 1999).

In feature research, my theoretical analysis should stimulate empirical research. Despite well-documented evidences of the working capital cost channel and implicit contracts, the relevance of their combination, the new cost channel, requires micro- and macro-evidences, which, in turn calls for econometric, experimental, or survey-type studies.

References

Akerlof, G. and J. Yellen, 1985, A Near-Rational Model of the Business Cycle with Price and Wage Inertia. *Quarterly Journal of Economics*, 100, 823-38.

Amirault, D., C. Kwan and G. Wilkinson, 2004, A Survey of the Price-Setting Behaviour of Canadian Companies. *Bank of Canada Review* 2004-2005, 29-40.

Apel, M., R. Friberg and K. Hallsten, 2005, Micro Foundations of Macroeconomic Price Adjustment: Survey Evidence from Swedish Firms. *Journal of Money, Credit, and Banking* 37, 313-38.

Ascari, G. 2004, Staggered Prices and Trend Inflation: Some Nuisances. *Review of Economic Dynamics* 7, 642—67.

Bakhshi, H, P. Burriel-Llombart, H. Khan and B. Rudolf, 2003, Endogenous Price Stickiness, Trend Inflation and the New Keynesian Phillips Curve. *Bank of England Working Paper* Nr. 191.

Ball, L. and G. N. Mankiw, 1994, A Sticky-Price Manifesto. *Carnegie-Rochester Conference Series on Public Policy* 41, 127-151.

Barth, M. J. III and V. A. Ramey, 2001, The Cost Channel of Monetary Transmission, in: *NBER Macroeconomic Annual 2001*, MA. pp. 199-239.

Blinder, A.S., E. Canetti, D.E. Lebow and J.B. Rudd, 1998, *Asking About Prices: A New Approach to Understanding Price Stickiness*, New York.

Calvo, G., 1983. Staggered Prices in a Utility-Maximizing Framework. *Journal of Monetary Economics* 12, 383-398.

Chowdhury, I., M. Hoffmann and A. Schabertb, 2006, Inflation Dynamics and the Cost Channel of Monetary Transmission. *European Economic Review* 50, 995-1016.

Christiano, L., M. Eichenbaum and C. Evans, 1999, Monetary Policy Shocks: What Have We Learned and to What End? in J. Taylor and M. Woodford (eds.), *Handbook of Macroeconomics*, Vol1A, Amsterdam. pp. 65-148.

Christiano, L., M. Eichenbaum and C. Evans, 2005, Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy* 113, 1-45.

Fabiani S. et al., 2005, The pricing behaviour of firms in the Euro Area: new survey evidence. *ECB Working Paper* Nr. 535.

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

Gaiotti, E. and A. Secchi, 2006, Is There a Cost Channel of Monetary Policy Transmission? An Investigation into the Pricing Behaviour of 2000 Firms. *Journal of Money, Credit, and Banking* forthcoming.

Hall, S., M. Walsh and A. Yates 2000, Are UK Companies' Prices Sticky? *Oxford Economic Papers* 52, 425-46.

Kiley, M., 2004, Is Moderate-to-High Inflation Inherently Unstable?. *The Federal Reserve Board, Finance and Economics Discussion Series* Nr. 43.

Klein, P., 2000, Using the Generalized Schur Form to Solve a Multivariate Linear Rational Expectations Model. *Journal of Economic Dynamics and Control* 24, 1405-23.

Konieczny, J. D. and A. Skrzypacz, 2006, Search, Costly Price Adjustment and the Frequency of Price Changes – Theory and Evidence. Unpublished Manuscript, Stanford University.

Lucas, R. E. Jr. 1972, Expectations and the Neutrality of Money. *Journal of Economic Theory* 4, 103-24.

Lucas, R. E. Jr. 1976, Econometric Policy Evaluation: A Critique. *Carnegie-Rochester Conference Series on Public Policy* 1, 19–46.

Mankiw, G. N. 1985, Small Menu Costs and Large Business Cycles: A Macroeconomic Model of Monopoly. *Quarterly Journal of Economics* 100, 529-38.

Mankiw, G. N. and R. Reis 2002, Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve. *Quarterly Journal of Economics* 117-4, 1295-1328.

McCallum, B. 2001, Software for RE Analysis. Computer software available at http://wpweb2k.gsia.cmu.edu/faculty/mccallum/research.html.

Okun, A., 1981, *Prices and Quantities: A Macroeconomic Analysis*, The Brookings Institution, Washington D.C..

Phelps, E. S., 1970, Introduction, in E.S. Phelps et al. *Microeconomic Foundations of Employment and Inflation Theory*, New York. 1-23.

Ravenna, F. and C. E. Walsh, 2006, Optimal Monetary Policy with the Cost Channel. *Journal of Monetary Economics* 53, 199-216.

Renner, E. and J. Tyran, 2004, Price Rigidity in Customer Markets. *Journal of Economic Behavior and Organization* 55, 575-93.

Rotemberg, J. J., 1982, Monopolistic Price Adjustment and Aggregate Output. *Review of Economic Studies* 49, 517-31.

Rotemberg, J. J., 2005, Customer Anger at Price Increases, Changes in the Frequency of Price Adjustment and Monetary Policy. *Journal of Monetary Economics* 52, 829-52.

Rotemberg, J. and M. Woodford, 1998, An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy: Extended Version. Working Paper No. t0233, *National Bureau of Economic Research.*

Sbordone Argia M, 2002, Prices and unit labor costs: A New Test of Price Stickiness. *Journal of Monetary Economics* 49, 265-292.

Schmitt-Grohé, S., M. Uribe, 2004, Optimal Simple and Implementable Monetary and Fiscal Rules. Working Paper Nr. w10253, *National Bureau of Economic Research.*

Taylor, J. B., 1980, Aggregate dynamics and staggered contracts. *Journal of Political Economy*, 88, 1—23

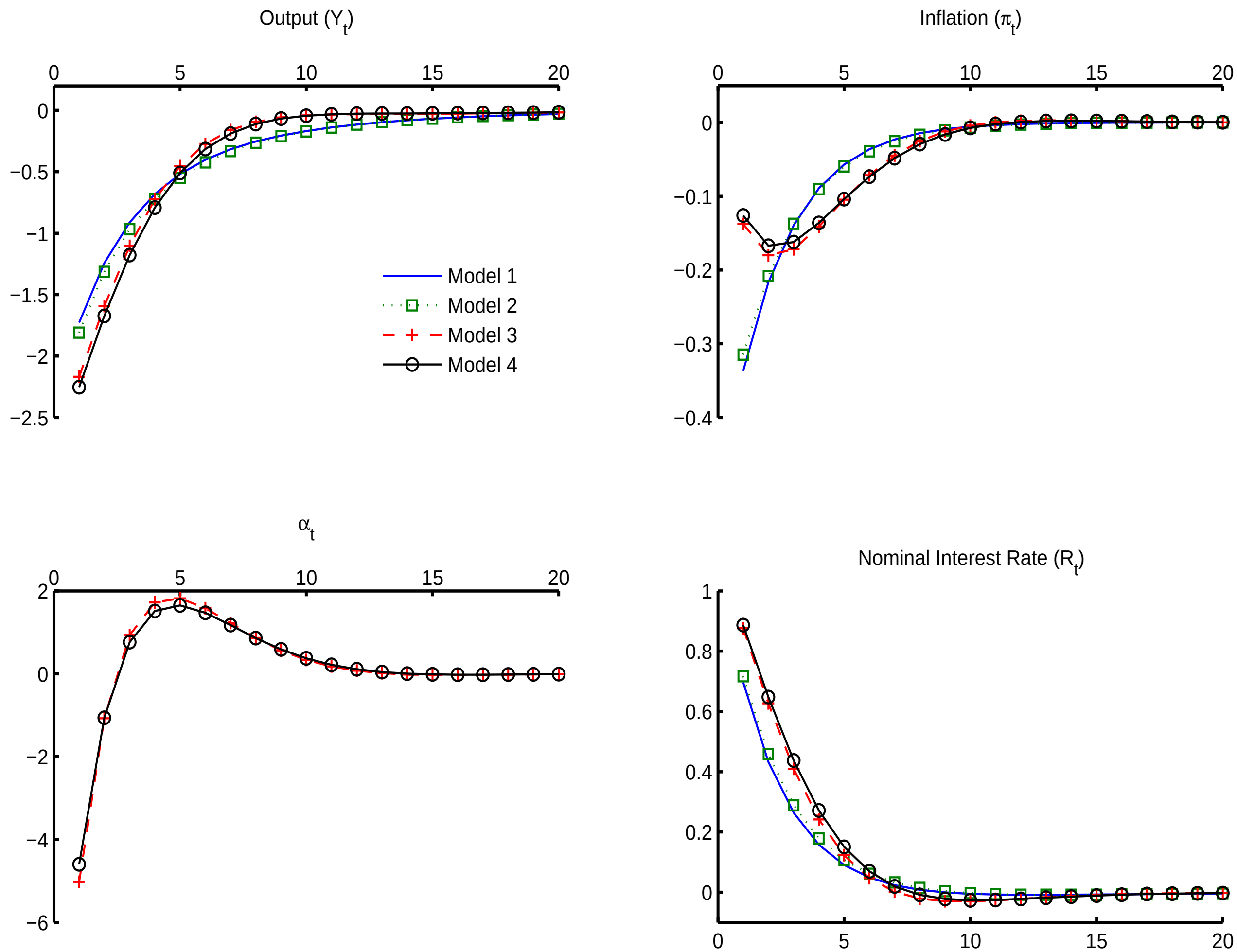
Taylor, J. B., 1993, Discretion versus Policy Rules in Practice. *Carnegie-Rochester Conference Series on Public Policy*, 39, 195-214.

Table 1: Calibrated parameters

A. Benchmark Economy	
Preferences	
	$\beta = 1.041^{-1/4}$
	$\sigma = 2/3$
	$\phi = 1$
	$\theta = 11$
Inflation, price rigidity	
and frequency of price adjustments	$\pi = 1.05^{1/4}$
	$X = 1.05$
	$\alpha = 0.7485$
	$\gamma_x = 2.5$
	$\gamma_\pi = -15$
	$\gamma_R = -10$
Monetary policy	
	$\rho_\pi = 0.9$
	$\rho_L = 0.9$

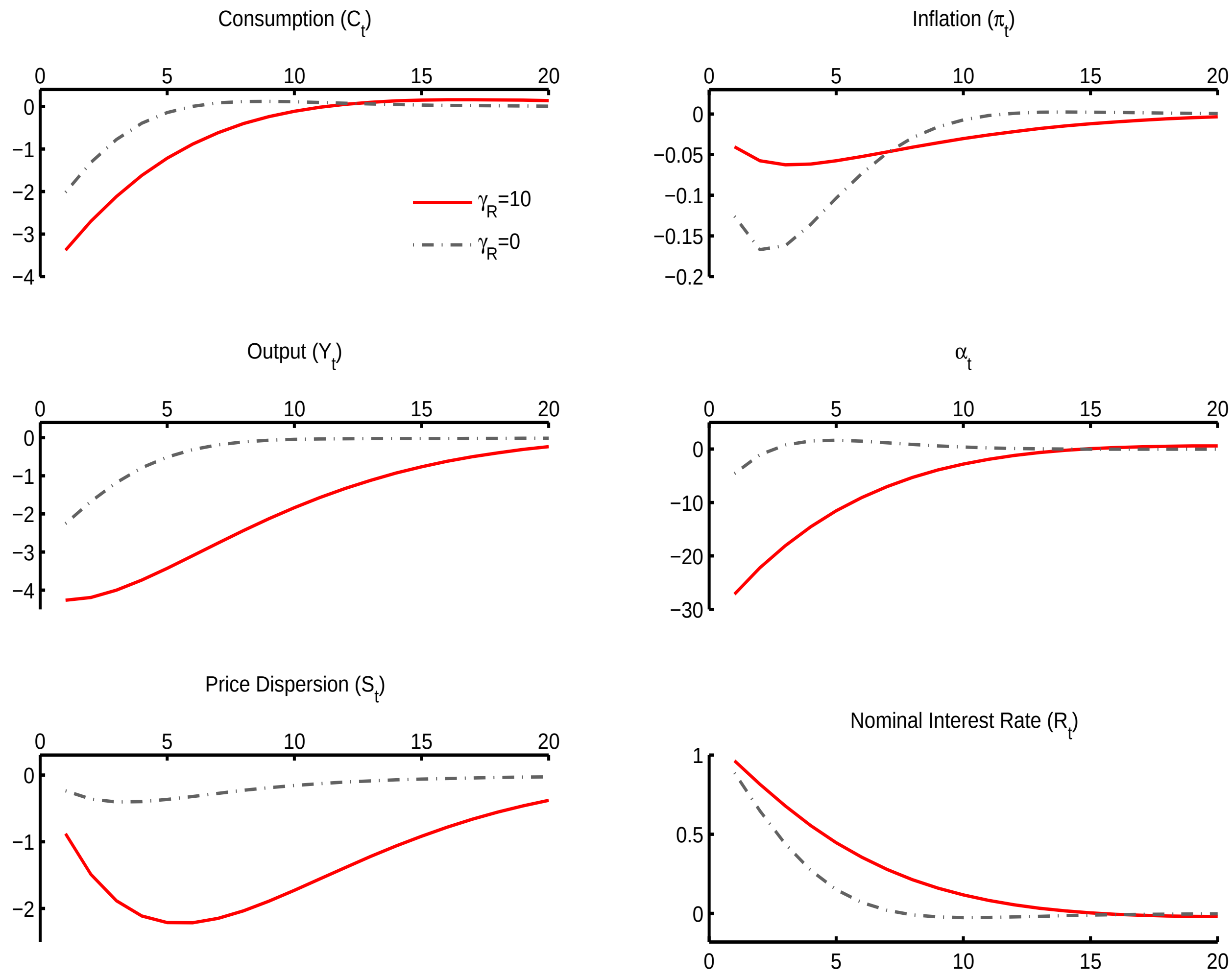
B. Sensitivity Analysis	
Parameter	*Range*
π	$1.05^{1/4} : 1.50^{1/4}$
γ_x	$0 : 3$
γ_π	$-25 : 0$
γ_R	$-20 : 0$
σ	$0.5 : 2$
ϕ	$0 : 2$
θ	$5 : 25$

Figure 1: Impulse responses to a contractionary monetary policy shock in four alternative models



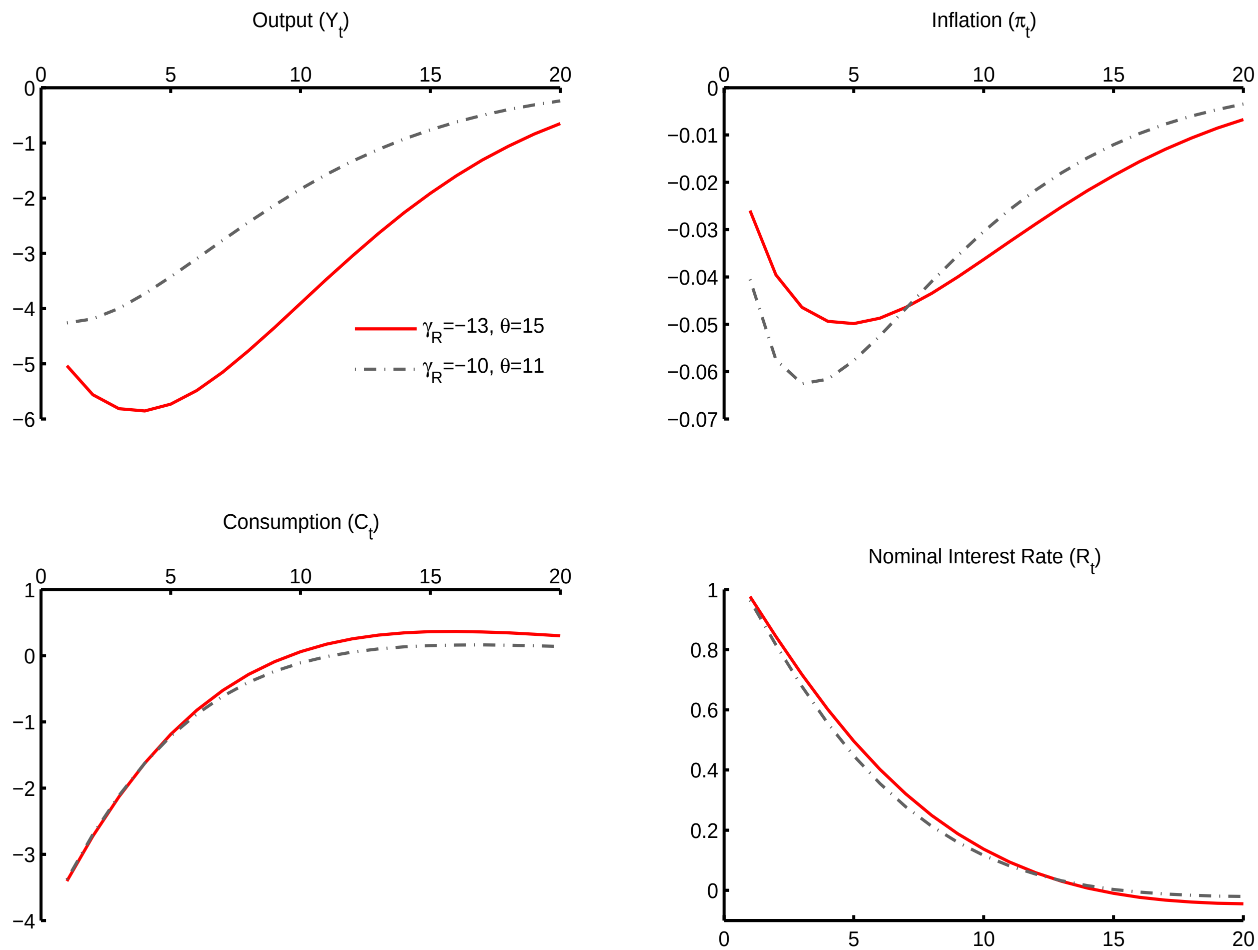
Note: The figure plots the responses of output, inflation, α_t, and nominal interest rate to a one percentage point positive shock to nominal interest rate. *Model 1:* New Keynesian Model with Calvo (1983) pricing. *Model 2:* Model 1 allowing the working capital cost channel. *Model 3:* Model 1 with Rotemberg (2005) pricing. *Model 4:* Model 3 allowing the working capital cost channel.

Figure 2: Impulse responses to a contractionary monetary policy shock in models of Section 2 and Rotemberg (2005)



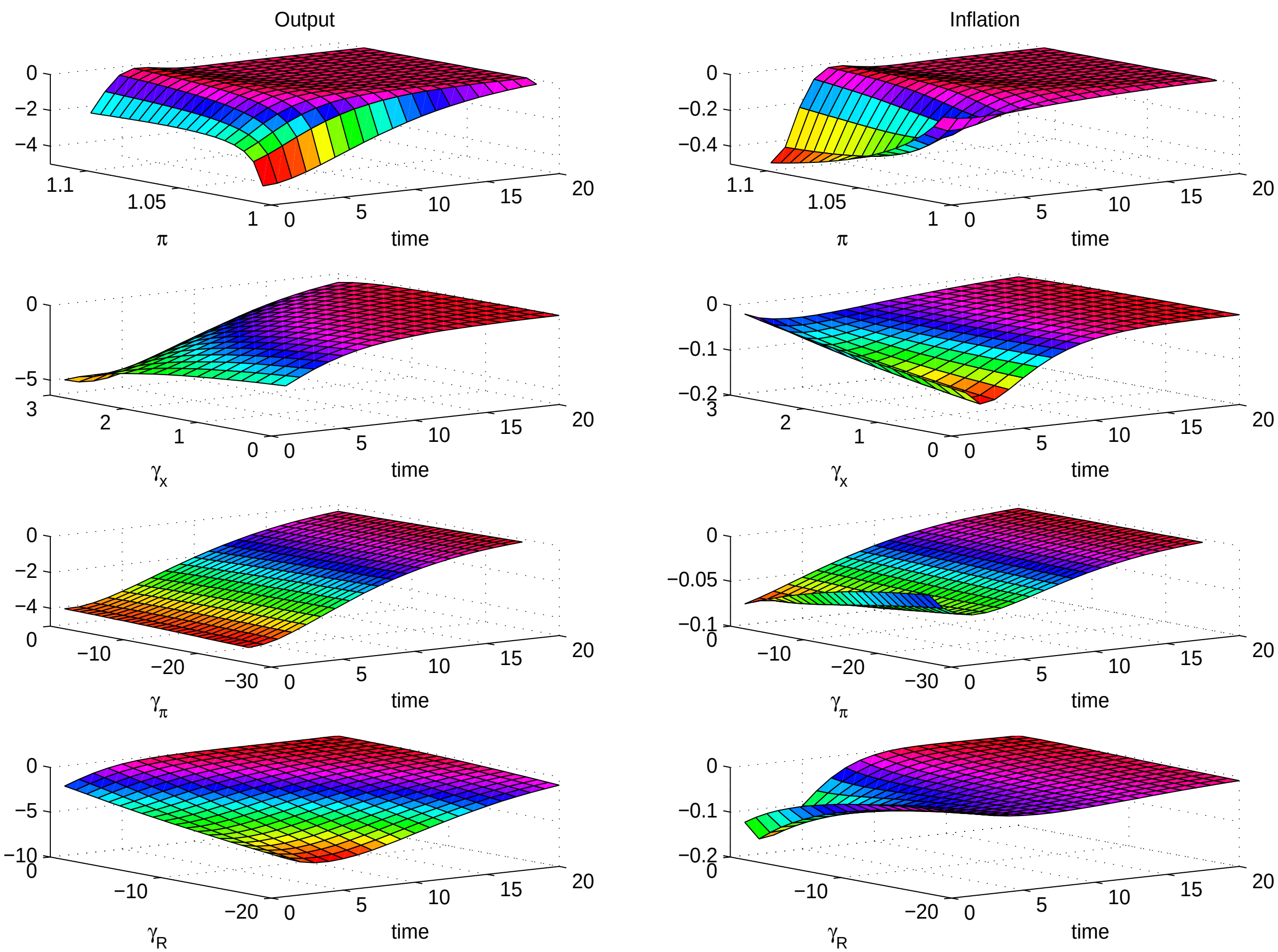
Note: The figure plots the responses of key variables to a one percentage point positive shock to nominal interest rate. While dot-dashed lines show responses in the Rotemberg model, solid lines show responses in the model of Section 2.

Figure 3: Impulse responses to a contractionary monetary policy shock for alternative parameterizations of γ_R and θ



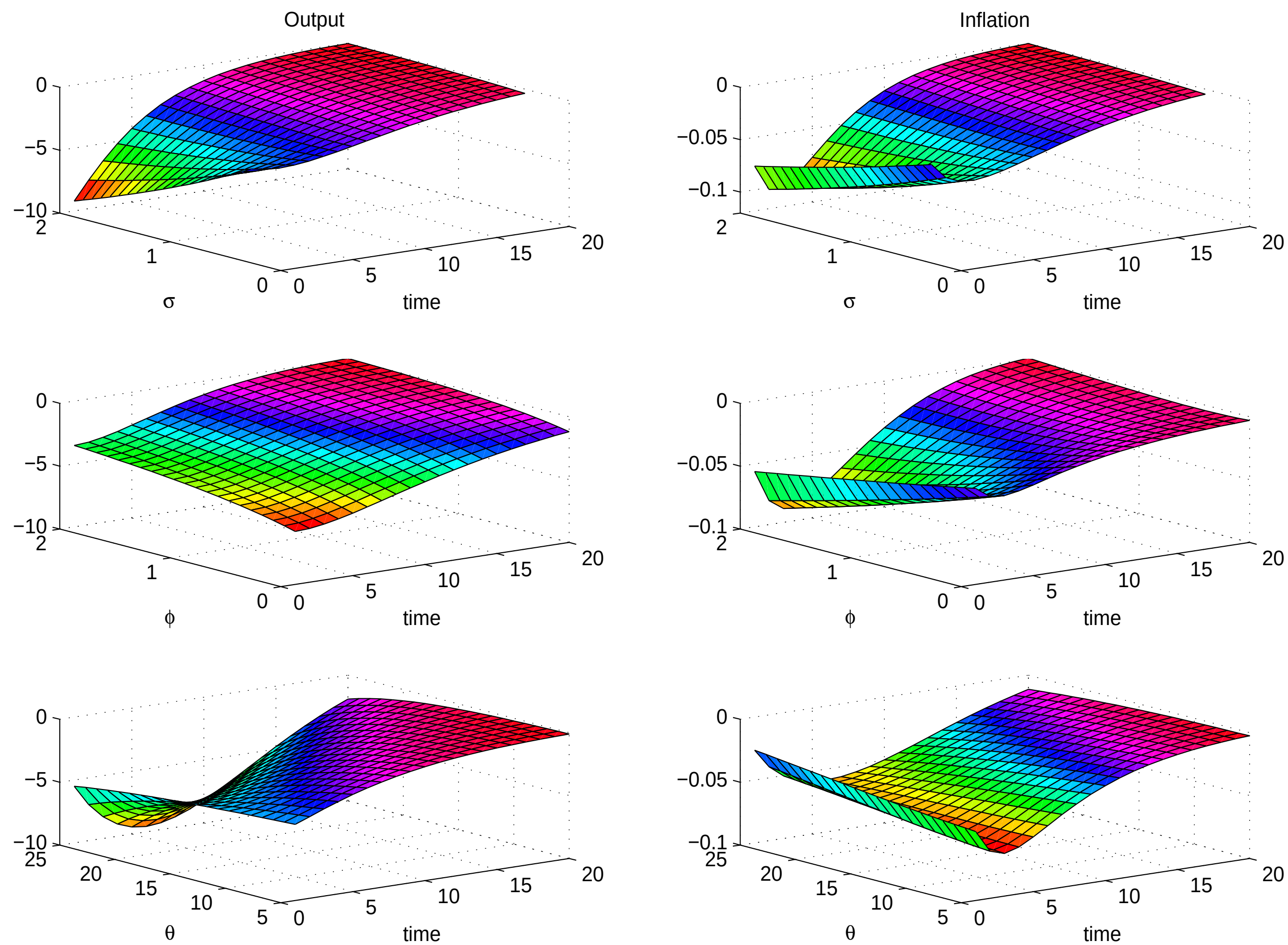
Note: The figure plots the responses in the model of Section 2 for $\gamma_R = -10$ and $\theta = 11$ (dot-dashed lines), and for $\gamma_R = -13$ and $\theta = 15$ (solid lines).

Figure 4: Sensitivity analyses for alternative values of π, γ_x, γ_π, and γ_R



Note: The figure plots the responses of output and inflation to a one percentage point positive shock to nominal interest rate, while from first to forth row $\pi \in [1.05^{1/4}, 1.50^{1/4}]$, $\gamma_x \in [0, 3]$, $\gamma_\pi \in [-25, 0]$, and $\gamma_R \in [-20, 0]$ vary on the northwest-southeast axis, respectively.

Figure 5: Sensitivity analyses for alternative values of values of σ, ϕ and θ



Note: The figure plots the responses of output and inflation to a one percentage point positive shock to nominal interest rate, while in the first, second and third row graphs, $\sigma \in [0.4, 2]$, $\phi \in [0, 2]$, and $\theta \in [-25, 0]$ vary on the northwest-southeast axis, respectively.