Optimal Monetary Policy with Sticky Office Rents*

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Abstract:

We argue that nominal rents for at least one form of capital, offices, are at least as rigid as the nominal prices and wages. We build a closed economy NNS model with two types of capital, offices and business capital, in order to investigate how office rent rigidity affects the design of the optimal monetary policy. Our findings suggest that an interest rate rule that reacts only to office rent inflation achieves levels of welfare that are remarkably close to the Ramsey optimal policy. We also find that when both price and wage rigidities exist, an interest rate rule that reacts only to office rent inflation outperforms interest rate rules that react to either price or wage inflation, regardless of whether the office rents are rigid.

Keywords: office rent rigidity, inflation targeting, monetary policy, welfare comparison, NNS model

JEL Classification Numbers: E52 (primary field), E32, R33

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"... *the key to the Keynesian theory of income determination is the assumption that the vector of prices, wages, and interest rates does not move instantaneously from one full employment equilibrium position to another.*"

Barro and Grossman (1971, p.82)

1 Introduction

The last decade has witnessed a tremendous growth in New Neoclassical Synthesis (NNS) models.[1] Within this class of models, nominal rigidity plays a central role in determining the optimal form of monetary policy. For instance, this literature concludes that when price (wage) rigidity is the only form of nominal rigidity, monetary policy should focus on stabilizing the price (wage) inflation rate.[2] However, when both prices and nominal wages are rigid, there are non-trivial tradeoffs between stabilizing price inflation, wage inflation and the output gap.[3] Given the importance of the form of nominal rigidity, it is somewhat surprising that in both the NNS models and the traditional Keynesian literature, little attention has been paid to the rigidity of the other nominal variable, the nominal rents of capital. One reason for this omission could be that the data for the nominal rents of capital are less readily available compared to prices and wages. This paper argues that the nominal rents for at least one form of capital, commercial real estate (referred to as "offices"[4]), are likely to be *at least* as rigid as prices and nominal wages. We then investigate how the rigidity of

[1] The name New Neoclassical Synthesis (NNS) was coined by Goodfriend and King (1997). Walsh (2003) and Woodford (2003) provide excellent introduction to this class of models.

[2] See for instance, Goodfriend and King (1997, 2001), King and Wolman (1996, 1999) and Khan et al. (2003) for the optimality of price inflation stabilization when the only form of nominal stickiness is price rigidity. For the case of nominal wage rigidity, see for instance, Erceg et al. (2000), Amato and Laubach (2003), Benigno and Woodford (2004) and Canzoneri et al. (2005).

[3] See for instance, Erceg et al. (2000), Amato and Laubach (2003), Benigno and Woodford (2004) and Canzoneri et al. (2005).

[4] In practice, "commercial real estate" includes not only "offices", but also "shopping malls", even "hotels". Since the focus of this paper is on the relative performance of different monetary policies, we ignore such subtle differences and use the terms "commerical real estate" and "office" interchangeably.

nominal office rents affects the design of the optimal monetary policy in a closed-economy NNS model.

While the exact degrees of price and wage rigidity remain an active topic of research, Taylor (1999) summarizes previous findings in this literature and concludes that the average frequency of price changes and wage changes are roughly the same, at about one year. On the other hand, microeconomic studies suggest that the leases on commercial real estate can be much longer than this. For instance, Sheehan (2006) analyzes a large data set of office lease negotiations in the US between 2001 and 2005 and finds that the mean term of office lease is 53 months with a median value of 60 months (Table 1). Similarly, Fisher and Ciochetti (2007) find that in their sample of 3,655 new office leases in the US between 2001 and 2005, half of the sample had lease lengths between 36 and 61 months, with a median value of 48 months. While the existing studies have not looked at whether office rents are fixed during the entire length of the lease, we believe that it is reasonable to speculate that most of the office rents are fixed for *at least* one year, just like the case of apartment rents.[5],[6] In the extreme, nominal office rents could be rigid for the entire length of the lease, which would be much longer than the duration of price and wage rigidities.

(Table 1 about here)

Given the importance of the form of nominal rigidity mentioned above, it is natural to ask how the rigidity of nominal office rents affects the design of the optimal monetary policy.[7] To answer this question, we construct a closed economy NNS model with two types of capital,

[5] For instance, Genesove (2003) reports that 45.8% of apartments for rent have leases of one year or more, and 39.3% have leases of less than a year, while 14.6% have no lease according to the 1993 Property Owners and Managers Survey. Genesove (2003) also reports that even during the high inflation period of 1974-1981, 29% of apartments in the Annual Housing Survey panel had no change of nominal rents from one year to the next.

[6] There is another complication for office leases in that they typically include many options, such as options for termination and reduction of space (Fisher and Ciochetti, 2007). However, we believe that these complexities do not affect the likely scenario that most office rents are fixed for at least one year.

[7] In a companion paper, we investigate how office rent rigidity affects the business cycle dynamics of an NNS model.

"offices" and business capital.[8] The nominal rents for offices are subjected to Calvo (1983)-style staggered adjustment, similar to prices and nominal wages. On the other hand, the nominal rents for business capital are assumed for simplicity to be flexible, since we do not have information about the extent of their stickiness. Given that office rents are rigid, we investigate whether the government should stabilize the nominal office rent inflation. We compare the performances of various interest rate rules that react to price inflation, wage inflation and office rent inflation, using the utility of the representative household as the welfare criterion. For comparison, we also compute the Ramsey-optimal policy.

The results of the model suggest that monetary policy should focus on stabilizing nominal office rent inflation when office rent rigidity exists along with price and wage rigidities. Under the Ramsey-optimal allocation, the standard deviation of office rent inflation is lower than the standard deviations of price and wage inflation when the three types of nominal rigidities exist simultaneously. Second, a simple interest rate rule that reacts only to office rent inflation (which we call a "flexible office rent inflation targeting rule") is only marginally worse than the Ramsey-optimal policy in all cases that we consider, with welfare differences typically less than 0.005% of the steady state consumption level. Third, perhaps somewhat surprisingly, we find that even when office rents are totally flexible, a flexible office rent inflation targeting rule continues to be superior to interest rate rules that react only to price inflation *or* wage inflation, and is only marginally worse than the Ramsey-optimal policy. The intuition behind this result is that a flexible office rent inflation targeting rule stabilizes a weighted average of the price and wage inflation in this model. We interpret these results as suggesting that the flexible office rent inflation targeting rule deserves serious consideration as a simple monetary policy rule that can improve welfare compared to conventional price inflation or wage inflation targeting rules. Finally, we find that a complete stabilization of price inflation leads to huge welfare costs in this model when the nominal wages are rigid

[8] Most macroeconomic models ignore commercial real estate. To our knowledge, Gort et al. (1999) is the only exception.

in addition to the prices, echoing the findings of Erceg et al. (2000) and Canzoneri et al. (2005).

The remainder of this paper is organized as follow. The model is presented in Section 2 and the welfare measure is discussed in Section 3. Section 4 discusses the solution method and calibration issues. We present the benchmark results in Section 5 and the robustness and sensitivity analysis in Section 6. Section 7 concludes.

2 The model

This section presents a closed economy NNS model with two types of capital, offices and business capital. Time is discrete and the horizon is infinite. There are several actors in this model economy. The representative household consumes non-durable goods and provides labor services in each period. The consumption goods are a composite of many differentiated products, each provided by a monopolistically competitive firm. Each firm hires labor and rents the business capital and offices from the representative household, and combines all the inputs to produce goods. The household collects factor payments and invests in both business capital and offices in a dynamically optimal manner. The consolidated government conducts monetary policy using a simple interest rate rule.

Prices, nominal wages and nominal office rents are subjected to Calvo (1983)-style staggered adjustment.[9] The nominal rents for business capital are assumed to be flexible for simplicity, since we do not have information about their degrees of stickiness. To facilitate comparison with the existing literature, we focus on the Woodford (2003) case of a "cashless" economy and assume that the government always balances the budget via lump sum

[9] We focus on the Calvo (1983)-style adjustment in order to facilitate comparison with existing studies since it is the most widely used mechanism in the NNS literature. However, it would be interesting to extend the current analysis to Taylor type contracting (Taylor 1993, 1999) and state-dependent pricing rules (Dotsey et al., 1999, Dotsey and King, 2005).

transfer, so that there is no fiscal policy consideration.[10]

2.1 Household

There is a representative household in the economy. The representative household maximizes expected lifetime utility with period utility defined over consumption, C_t and labor hours, H_t. Period utility is specified as separable in consumption and labor hours:

$$E_0 \sum_{t=0}^{\infty} \beta^t u(C_t, H_t), \tag{1}$$

$$u(C_t, H_t) = \frac{C_t^{1-\sigma} - 1}{1-\sigma} - \gamma \frac{H_t^{1+\xi}}{1+\xi}, \tag{2}$$

where E_t is the expectations operator conditional on period t information, $\beta \in (0,1)$ is the subjective discount factor, $\sigma > 0$ is the coefficient of risk aversion, $\xi \geq 0$ is the inverse of Frisch labor supply elasticity, and $\gamma > 0$ is a preference parameter.

The consumption good is a constant elasticity of substitution (CES) composite of a continuum, indexed by $i \in [0,1]$, of differentiated goods, $C_{i,t}$:

$$C_t = \left[\int_0^1 C_{i,t}^{\frac{\eta_y - 1}{\eta_y}} di \right]^{\frac{\eta_y}{\eta_y - 1}}, \tag{3}$$

where $\eta_y > 1$ is the elasticity of substitution across differentiated goods. Cost minimization by the representative household leads to the following demand function for $C_{i,t}$:

$$C_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\eta_y} C_t, \tag{4}$$

[10] As explained in Woodford (2003), the "cashless" economy is similar to a setup where money demand is introduced by adding a real money balance term in the utility that is separable from consumption and leisure. Results from Schmitt-Grohé and Uribe (2004a, 2006a,c, 2007) suggest that introducing money demand through either a cash-in-advance constraint or a shopping time framework is likely to change only the steady state inflation rate slightly, without having a large effect on the dynamics of the optimal monetary policy.

where $P_{i,t}$ is the price of variety i goods and P_t is a price index given by:

$$P_t \equiv \left[\int_0^1 (P_{i,t})^{1-\eta_y} \, di \right]^{1/(1-\eta_y)} . \tag{5}$$

Following Schmitt-Grohé and Uribe (2005, 2006a,b), the representative household is assumed to supply labor monopolistically to a continuum of labor markets, indexed by $j \in [0, 1]$. In each labor market j, the nominal wage charged by the representative household is denoted by $W_{j,t}$. Similar to the case of consumption goods, the differentiated labor services, $H_{j,t}$, are aggregated into a CES composite of labor input, H_t^d, that is used by firms for production:

$$H_t^d = \left[\int_0^1 H_{j,t}^{\frac{\eta_h - 1}{\eta_h}} \, dj \right]^{\frac{\eta_h}{\eta_h - 1}} , \tag{6}$$

where η_h is the elasticity of substitution across differentiated labor services. Cost minimization by firms leads to the following demand function for $H_{j,t}$:

$$H_{j,t} = \left(\frac{W_{j,t}}{W_t} \right)^{-\eta_h} H_t^d, \tag{7}$$

where W_t is a wage index given by:

$$W_t \equiv \left[\int_0^1 (W_{j,t})^{1-\eta_h} \, dj \right]^{1/(1-\eta_h)} . \tag{8}$$

Equation (7) can also be written as:

$$H_{j,t} = \left(\frac{w_{j,t}}{w_t} \right)^{-\eta_h} H_t^d, \tag{9}$$

where $w_{j,t} \equiv W_{j,t}/P_t$ and $w_t \equiv W_t/P_t$ are the real wage rate for variety j labor input and the real wage index, respectively. In addition, the sum of the supply of labor services in all labor markets equals total labor supply, H_t:

$$\int_0^1 H_{j,t} dj = \int_0^1 \left(\frac{w_{j,t}}{w_t} \right)^{-\eta_h} H_t^d dj = H_t. \tag{10}$$

The representative household owns business capital, K_t, and office, F_t, which evolve according to the laws of motion:

$$K_{t+1} = (1 - \delta_k) K_t + I_{k,t} - \frac{\phi_k}{2} \frac{(K_{t+1} - K_t)^2}{K_t}, \tag{11}$$

$$F_{t+1} = (1 - \delta_f) F_t + I_{f,t} - \frac{\phi_f}{2} \frac{(F_{t+1} - F_t)^2}{F_t}, \tag{12}$$

where $I_{k,t}$ and $I_{f,t}$ are the gross business capital and office investments, respectively; $\frac{\phi_k}{2} \frac{(K_{t+1}-K_t)^2}{K_t}$ and $\frac{\phi_f}{2} \frac{(F_{t+1}-F_t)^2}{F_t}$, with $\phi_k, \phi_f > 0$, are quadratic capital adjustment costs. $\delta_k, \delta_f \in (0, 1)$ are the depreciation rates of business capital and offices. For simplicity, the investment goods for business capital and offices are assumed to be CES composites of differentiated goods, similar to consumption in equation (3). Business capital is rented to firms as an input for production at the nominal rental rate R_t^k. As mentioned above, R_t^k is assumed to be *flexible.*

The markets for offices are modeled in a way analogous to the markets for labor. Specifically, the representative household is assumed to supply offices monopolistically to a continuum of office markets, indexed by $z \in [0, 1]$. In each office market z, the nominal rent charged by the representative household is denoted by $R_{z,t}^f$. The differentiated office, $F_{z,t}$, is aggregated into a CES composite of office input, F_t^d, which is used by firms for production:

$$F_t^d = \left[\int_0^1 F_{z,t}^{\frac{\eta_f - 1}{\eta_f}} dz \right]^{\frac{\eta_f}{\eta_f - 1}}, \tag{13}$$

where η_f is the elasticity of substitution across differentiated offices. Cost minimization by firms leads to the following demand function for $F_{z,t}$:

$$F_{z,t} = \left(\frac{R^f_{z,t}}{R^f_t} \right)^{-\eta_f} F^d_t, \tag{14}$$

where R^f_t is an office rent index given by:

$$R^f_t \equiv \left[\int_0^1 \left(R^f_{z,t} \right)^{1-\eta_f} dz \right]^{1/(1-\eta_f)}. \tag{15}$$

Equation (14) can also be written as:

$$F_{z,t} = \left(\frac{r^f_{z,t}}{r^f_t} \right)^{-\eta_f} F^d_t, \tag{16}$$

where $r^f_{z,t} \equiv R^f_{z,t}/P_t$ and $r^f_t \equiv R^f_t/P_t$ are the real rental rate for variety z office and the real office rent index, respectively. In addition, the sum of the supply of offices in all office markets equals total office supply, F_t:

$$\int_0^1 F_{z,t} dq = \int_0^1 \left(\frac{r^f_{z,t}}{r^f_t} \right)^{-\eta_f} F^d_t dq = F_t. \tag{17}$$

The period-by-period budget constraint of the representative household is given by:

$$\frac{B_t}{P_t} + C_t + I_{k,t} + I_{f,t} = R_{t-1} \frac{B_{t-1}}{P_t} + \int_0^1 w_{j,t} H_{j,t} dj + r^k_t K_t + \int_0^1 r^f_{z,t} F_{z,t} dz + D_t, \tag{18}$$

where B_t is a riskless one-period nominal bond, bought in period t and maturing in period $t+1$; R_t is the gross nominal interest rate on the riskless bond; $r^k_t \equiv R^k_t/P_t$ is the real rental rate for business capital; D_t is the real dividend from owning all firms in the economy. Substituting $I_{k,t}$ and $I_{f,t}$ from equations (11) and (12) into the budget constraint (18), the representative household's optimization problem consists of choosing C_t, B_t, H_t, K_{t+1}, F_{t+1},

$W_{j,t}$ and $R^f_{z,t}$ to maximize the intertemporal utility, (1), subject to the budget constraint (18) and resource constraints (10) and (17). The first order conditions with respect to C_t, B_t, H_t, K_{t+1} and F_{t+1} are:

$$\frac{1}{C_t^{\sigma}} = \lambda_t, \tag{19}$$

$$\lambda_t = \beta E_t \frac{\lambda_{t+1}}{\pi_{t+1}} R_t, \tag{20}$$

$$\gamma H_t^{\xi} = \lambda_t^h, \tag{21}$$

$$\begin{aligned} & \beta E_t \lambda_{t+1} r^k_{t+1} + \beta E_t \lambda_{t+1} (1-\delta_k) + \beta E_t \lambda_{t+1} \left[\phi_k \frac{K_{t+2} - K_{t+1}}{K_{t+1}} + \frac{\phi_k}{2} \frac{(K_{t+2} - K_{t+1})^2}{K^2_{t+1}} \right] \\ = \; & \lambda_t \left(1 + \phi_k \frac{K_{t+1} - K_t}{K_t} \right), \end{aligned} \tag{22}$$

$$\begin{aligned} & \beta E_t \lambda^{Rf}_{t+1} + \beta E_t \lambda_{t+1} (1-\delta_f) + \beta E_t \lambda_{t+1} \left[\phi_f \frac{F_{t+2} - F_{t+1}}{F_{t+1}} + \frac{\phi_f}{2} \frac{(F_{t+2} - F_{t+1})^2}{F^2_{t+1}} \right] \\ = \; & \lambda_t \left(1 + \phi_f \frac{F_{t+1} - F_t}{F_t} \right), \end{aligned} \tag{23}$$

where λ_t is the Lagrange multiplier associated with the budget constraint, (18); λ_t^h and λ_t^{Rf} are the Lagrange multipliers associated with the resource constraints (10) and (17), respectively; $\pi_t \equiv P_t/P_{t-1}$ is the gross price inflation rate.

Wage setting is staggered, à la Calvo (1983). In each labor market j, each period, the representative household faces a random probability $(1-\alpha_h)$, $\alpha_h \in [0,1]$, of resetting the nominal wage, $W_{j,t}$. If $W_{j,t}$ is not reset, it is updated by the last period's gross price inflation rate, π_{t-1}, according to the rule $W_{j,t} = \pi_{t-1}^{\chi_h} W_{j,t-1}$, where $\chi_h \in [0,1]$ is the degree of indexation for nominal wages. $\chi_h = 0$ corresponds to no wage indexation, which is the case considered by Amato and Laubach (2003); $\chi_h = 1$ corresponds to full wage indexation, which is the case considered by Christiano et al. (2005) and Schmitt-Grohé and Uribe

(2005, 2006a,b). Let $\tilde{W}_t$ denote the new wage that is reset in period t and $\tilde{w}_t \equiv \tilde{W}_t/P_t$. After setting a new wage at period t, there is α_h^τ probability that the nominal wage has not been reset at period $t+\tau$, and hence $W_{j,t+\tau} = \tilde{W}_t \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_h}$, or equivalently, $w_{j,t+\tau} = \tilde{w}_t \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_h}/\pi_{t+\kappa}$. Making use of the wage updating rule and the demand equation, (9), the Lagrangian for the wage optimization problem (with only consequential terms) is:

$$\pounds^W = E_t \sum_{\tau=0}^{\infty} (\alpha_h \beta)^\tau \left[\begin{array}{c} -\lambda_{t+\tau}^h \left(\frac{\tilde{w}_t}{w_{t+\tau}} \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_h}/\pi_{t+\kappa} \right)^{-\eta_h} H_{t+\tau}^d \\ +\lambda_{t+\tau}\tilde{w}_t \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_h}/\pi_{t+\kappa} \left(\frac{\tilde{w}_t}{w_{t+\tau}} \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_h}/\pi_{t+\kappa} \right)^{-\eta_h} H_{t+\tau}^d \end{array} \right]. \tag{24}$$

The first order condition with respect to $\tilde{w}_t$, after substituting for λ_t^h using equation (21), is:

$$\tilde{w}_t = \frac{\eta_h}{\eta_h - 1} \frac{\sum_{\tau=0}^{\infty} (\alpha_h \beta)^\tau \gamma H_{t+\tau}^{\xi} \left(w_{t+\tau} \prod_{k=1}^{\tau} \frac{\pi_{t+\kappa}}{\pi_{t+k-1}^{\chi_h}} \right)^{\eta_h} H_{t+\tau}^d}{\sum_{\tau=0}^{\infty} (\alpha_h \beta)^\tau \lambda_{t+\tau} (w_{t+\tau})^{\eta_h} \left(\prod_{k=1}^{\tau} \frac{\pi_{t+\kappa}}{\pi_{t+k-1}^{\chi_h}} \right)^{\eta_h - 1} H_{t+\tau}^d}. \tag{25}$$

Rent rigidity for offices is modeled analogous to wage rigidity. It is assumed that in each office market z, each period, the representative household faces a random probability $(1-\alpha_f)$, $\alpha_f \in [0,1]$, of resetting the nominal rental rate, $R_{z,t}^f$. If $R_{z,t}^f$ is not reset, it is updated by the last period's gross price inflation rate, π_{t-1}, according to the rule $R_{z,t}^f = \pi_{t-1}^{\chi_f} R_{z,t-1}^f$, where $\chi_f \in [0,1]$ is the degree of indexation for nominal office rent. Let $\widetilde{R}_{z,t}^f$ denote the new office rent that is reset in period t and $\tilde{r}_t^f \equiv \widetilde{R}_{z,t}^f/P_t$. After setting the rent at period t, there is α_f^τ probability that the nominal office rent has not been reset at period $t+\tau$, and hence $R_{z,t+\tau}^f = \widetilde{R}_{z,t}^f \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_f}$, or equivalently, $r_{j,t+\tau}^f = \tilde{r}_t^f \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_f}/\pi_{t+\kappa}$. Making use of the nominal rent updating rule and the demand equation (16), the Lagrangian for the office rent optimization problem (with only consequential terms) is:

$$\pounds^f = E_t \sum_{\tau=0}^{\infty} (\alpha_f \beta)^\tau \left[\begin{array}{c} -\lambda^{Rf}_{t+\tau} \left(\frac{\tilde{r}^f_t}{r^f_{t+\tau}} \prod_{k=1}^{\tau} \pi^{\chi_f}_{t+k-1}/\pi_{t+\kappa} \right)^{-\eta_f} F^d_{t+\tau} \\ +\lambda_{t+\tau} \tilde{r}^f_t \prod_{k=1}^{\tau} \pi^{\chi_f}_{t+k-1}/\pi_{t+\kappa} \left(\frac{\tilde{r}^f_t}{r^f_{t+\tau}} \prod_{k=1}^{\tau} \pi^{\chi_f}_{t+k-1}/\pi_{t+\kappa} \right)^{-\eta_f} F^d_{t+\tau} \end{array} \right]. \tag{26}$$

The first order condition with respect to $\tilde{r}^f_t$ is:

$$\tilde{r}^f_t = \frac{\eta_f}{\eta_f - 1} \frac{\sum_{\tau=0}^{\infty} (\alpha_f \beta)^\tau \lambda^{Rf}_{t+\tau} \left(r^f_{t+\tau} \prod_{\kappa=1}^{\tau} \frac{\pi_{t+k}}{\pi^{\chi_f}_{t+k-1}} \right)^{\eta_f} F^d_{t+\tau}}{\sum_{\tau=0}^{\infty} (\alpha_f \beta)^\tau \lambda_{t+\tau} \left(r^f_{t+\tau} \right)^{\eta_f} \left(\prod_{\kappa=1}^{\tau} \frac{\pi_{t+k}}{\pi^{\chi_f}_{t+k-1}} \right)^{\eta_f - 1} F^d_{t+\tau}}. \tag{27}$$

2.2 Firms

There is a continuum of monopolistically competitive firms, indexed by $i \in [0, 1]$. Following Gort et al. (1999), firm i's production technology is given by:

$$A_t (K_{i,t})^{\theta_1} (F^d_{i,t})^{\theta_2} (H^d_{i,t})^{1-\theta_1-\theta_2},$$

where $K_{i,t}$, $F^d_{i,t}$ and $H^d_{i,t}$ are respectively the amounts of business capital, office and labor input used by firm i. $\theta_1, \theta_2 \geq 0$ are the shares of business capital and offices, respectively. A_t is the aggregate technology process, which evolves according to the law of motion:

$$\ln A_t = \rho^A \ln A_{t-1} + \varepsilon^A_t, \tag{28}$$

where $\rho^A \in (0, 1)$ is the first order autoregressive parameter and ε^A_t is an i.i.d. shock with standard deviation, σ_{ε^A}.

Given the demand function for $C_{i,t}$, equation (4), and the counterpart for investment $I_{k,t}$

and $I_{f,t}$, the demand for firm i's goods, $Y_{i,t}$, is given by:

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\eta_y} Y_t = p_{i,t}^{-\eta_y} Y_t, \tag{29}$$

where $p_{i,t} \equiv P_{i,t}/P_t$ and

$$Y_t \equiv C_t + I_{k,t} + I_{f,t}. \tag{30}$$

Firm i chooses $K_{i,t}$, $F^d_{i,t}$ and $H^d_{i,t}$ to minimize the cost of production subject to the constraint that the supply is able to meet the demand, $Y_{i,t}$:

$$\min r^k_t K_{i,t} + r^f_t F^d_{i,t} + w_t H^d_{i,t} \tag{31}$$

$$\text{s.t. } A_t(K_{i,t})^{\theta_1}(F^d_{i,t})^{\theta_2}(H^d_{i,t})^{1-\theta_1-\theta_2} \geq Y_{i,t}. \tag{32}$$

The first order conditions for the cost minimization problem are:

$$r^k_t = \theta_1 mc_t A_t(K_{i,t})^{\theta_1-1}(F^d_{i,t})^{\theta_2}(H^d_{i,t})^{1-\theta_1-\theta_2}, \tag{33}$$

$$r^f_t = \theta_2 mc_t A_t(K_{i,t})^{\theta_1}(F^d_{i,t})^{\theta_2-1}(H^d_{i,t})^{1-\theta_1-\theta_2}, \tag{34}$$

$$w_t = (1-\theta_1-\theta_2)\, mc_t A_t(K_{i,t})^{\theta_1}(F^d_{i,t})^{\theta_2}(H^d_{i,t})^{-\theta_1-\theta_2}, \tag{35}$$

where mc_t is the Lagrange multiplier associated with equation (32), which can be interpreted as the real marginal cost.[11]

Similar to the case of wages and office rents, it is assumed that in each period, each firm faces a random probability $(1-\alpha_y)$, $\alpha_y \in (0,1)$ of resetting the nominal price, $P_{i,t}$. If $P_{i,t}$ is not reset, it is updated by the last period's gross price inflation rate, π_{t-1}, according to the rule $P_{i,t} = \pi^{\chi_y}_{t-1} P_{i,t-1}$, where $\chi_y \in [0,1]$ is the degree of indexation for nominal prices. Let

[11] Given the structure of the model, marginal cost will be equalized across firms, so there is no subscript i on mc_t.

$\tilde{P}_t$ denote the new price that is reset in period t and $\tilde{p}_t \equiv \tilde{P}_t/P_t$. After setting the price at period t, there is α_y^τ probability that the nominal price has not been reset at period $t+\tau$, and hence $P_{i,t+\tau} = \tilde{P}_t \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_y}$, or equivalently, $p_{i,t+\tau} = \tilde{p}_t \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_y}/\pi_{t+k}$. Making use of the price updating rule and the demand equation, (29), the price optimization problem for firm i is:

$$\max_{\tilde{p}_t} E_t \sum_{\tau=0}^{\infty} \alpha_y^\tau \rho_{t,t+\tau} \left(\tilde{p}_t \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_y}/\pi_{t+k} \left(\tilde{p}_t \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_y}/\pi_{t+k} \right)^{-\eta_y} Y_{t+\tau} \right.$$
$$\left. -TC\left(\left(\tilde{p}_t \prod_{k=1}^{\tau} \pi_{t+k-1}^{\chi_y}/\pi_{t+k} \right)^{-\eta_y} Y_{t+\tau} \right) \right), \tag{36}$$

where $\rho_{t,t+\tau} = \beta^\tau \lambda_{t+\tau}/\lambda_t$ is a discount factor for profit. $TC(\cdot)$ is the real total cost as a function of output. The first order condition is:

$$\tilde{p}_t = \frac{\eta_y}{\eta_y - 1} \frac{E_t \sum_{\tau=0}^{\infty} \alpha_y^\tau \rho_{t,t+\tau} mc_{t+\tau} \left(\prod_{\kappa=1}^{\tau} \frac{\pi_{t+k}}{\pi_{t+k-1}^{\chi_y}} \right)^{\eta_y} Y_{t+\tau}}{E_t \sum_{\tau=0}^{\infty} \alpha_y^\tau \rho_{t,t+\tau} \left(\prod_{\kappa=1}^{\tau} \frac{\pi_{t+k}}{\pi_{t+k-1}^{\chi_y}} \right)^{\eta_y - 1} Y_{t+\tau}}. \tag{37}$$

2.3 Market clearing and aggregation

In equilibrium, the total net supply of bond is zero:

$$B_t = 0. \tag{38}$$

The total demand of business capital, office and labor inputs across all firms must equal their supply:

$$\int_0^1 K_{i,t} di = K_t, \tag{39}$$

$$\int_0^1 F_{i,t}^d di = F_t^d, \tag{40}$$

$$\int_0^1 H_{i,t}^d di = H_t^d. \tag{41}$$

Making use of the three equilibrium conditions above, and the equilibrium condition that the ratio of factor inputs is equalized across firms because of the Cobb-Douglas production function, equations (33) to (35) can be aggregated as:

$$r_t^k = \theta_1 mc_t A_t (K_t)^{\theta_1 - 1} (F_t^d)^{\theta_2} (H_t^d)^{1-\theta_1-\theta_2}, \tag{42}$$

$$r_t^f = \theta_2 mc_t A_t (K_t)^{\theta_1} (F_t^d)^{\theta_2 - 1} (H_t^d)^{1-\theta_1-\theta_2}, \tag{43}$$

$$w_t = (1-\theta_1-\theta_2)\, mc_t A_t (K_t)^{\theta_1} (F_t^d)^{\theta_2} (H_t^d)^{-\theta_1-\theta_2}. \tag{44}$$

The random probability of adjusting prices, wages and rents allow us to write their indices, equations (5), (8) and (15), as:

$$1 = \alpha_y \left(\pi_{t-1}^{\chi_y} \frac{1}{\pi_t} \right)^{1-\eta_y} + (1-\alpha_y) \left(\widetilde{p}_t \right)^{1-\eta_y}, \tag{45}$$

$$(w_t)^{1-\eta_h} = \alpha_h \left(\pi_{t-1}^{\chi_h} \frac{w_{t-1}}{\pi_t} \right)^{1-\eta_h} + (1-\alpha_h) \left(\widetilde{w}_t \right)^{1-\eta_h}, \tag{46}$$

$$\left(r_t^f \right)^{1-\eta_f} = \alpha_f \left(\pi_{t-1}^{\chi_f} \frac{r_{t-1}^f}{\pi_t} \right)^{1-\eta_f} + (1-\alpha_f) \left(\tilde{r}_t^f \right)^{1-\eta_f}. \tag{47}$$

In equilibrium, equation (32) holds with equality. Combining equations (29) and (32) and aggregating the resulting equation across firms, we have:[12]

$$A_t (K_t)^{\theta_1} (F_t^d)^{\theta_2} (H_t^d)^{1-\theta_1-\theta_2} = s_{y,t} Y_t, \tag{48}$$

where

$$s_{y,t} \equiv \int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{-\eta_y} di. \tag{49}$$

[12]In the equation below, we have made use of the fact that ratio of factor inputs is identical across firms in this model.

As noted in Schmitt-Grohé and Uribe (2004a, 2005, 2006c, 2007) and Khan et al. (2003), $s_{y,t}$ is a measure of the resource cost of price dispersion associated with the Calvo-style price setting, and it can be shown that $s_{y,t} \geq 1$. Higher values of $s_{y,t}$ correspond to a higher resource cost of price dispersion, as a given combination of total capital and labor inputs gives rise to a smaller amount of aggregate output, Y_t. Similar to the case of the price index, given the random nature of price adjustments, $s_{y,t}$ can be written recursively as:

$$s_{y,t} = \alpha_y \left(\pi_{t-1}^{\chi_y}/\pi_t\right)^{-\eta_y} s_{y,t-1} + (1-\alpha)\left(\widetilde{p}_t\right)^{-\eta_y}. \tag{50}$$

Similarly, equations (10) and (17) can be written as:

$$H_t = s_{h,t} H_t^d, \tag{51}$$

$$F_t = s_{f,t} F_t^d, \tag{52}$$

where

$$s_{h,t} \equiv \int_0^1 \left(\frac{w_{j,t}}{w_t}\right)^{-\eta_h} dj, \tag{53}$$

$$s_{f,t} \equiv \int_0^1 \left(\frac{r_{z,t}^f}{r_t^f}\right)^{-\eta_f} dz. \tag{54}$$

Similar to the case of prices, $s_{h,t}$ and $s_{f,t}$ are measures of the resource costs of wage and office rent dispersion associated with the Calvo-style wage and office rent setting. It can also be shown that $s_{h,t}, s_{f,t} \geq 1$. Higher values of $s_{h,t}$ and $s_{f,t}$ correspond to higher resource costs of wage and office rent dispersion, respectively, since a given supply of labor and office, H_t and F_t, will give rise to a smaller amount of labor and office input, H_t^d and F_t^d. Similar to the case of $s_{y,t}$, equations (53) and (54) can be written recursively as:

$$s_{h,t} = \alpha_h \left(\frac{\pi_{t-1}^{\chi_h}}{\pi_t}\frac{w_{t-1}}{w_t}\right)^{-\eta_h} s_{h,t-1} + (1-\alpha_h)\left(\frac{\widetilde{w}_t}{w_t}\right)^{-\eta_h}, \tag{55}$$

$$s_{f,t} = \alpha_f \left(\frac{\pi_{t-1}^{\chi_f}}{\pi_t} \frac{r_{t-1}^f}{r_t^f} \right)^{-\eta_f} s_{f,t-1} + (1-\alpha_f) \left(\frac{\tilde{r}_t^f}{r_t^f} \right)^{-\eta_h} . \tag{56}$$

Finally, it is assumed that all profits are distributed as dividend to the household who owns the firms, so the real dividend D_t equals:

$$D_t \equiv \int_0^1 \left(\frac{P_{i,t}}{P_t} Y_{i,t} - r_t^k K_{i,t} - r_t^f F_{i,t}^d - w_t H_{i,t}^d \right) di. \tag{57}$$

Making use of equations (5), (29), and (39) to (41), D_t can be aggregated as:

$$D_t = Y_t - r_t^k K_t - r_t^f F_t^d - w_t H_t^d. \tag{58}$$

2.4 Monetary policy

Following Schmitt-Grohé and Uribe (2004a, 2005, 2006a,b,c, 2007), we assume that the consolidated government conducts monetary policy using a simple feedback rule, belonging to the class of Taylor (1993)-type interest rate rules, where the nominal interest rate reacts to the deviations of a small set of macroeconomic variables from their targets. The interest rate rules that we consider are of one of the following forms:

$$\ln(R_t/R^*) = \Gamma_p \ln(\pi_t/\pi^*), \tag{59}$$

$$\ln(R_t/R^*) = \Gamma_w \ln(\pi_t^w/\pi^{w*}), \tag{60}$$

$$\ln(R_t/R^*) = \Gamma_f \ln\left(\pi_t^{Rf}/\pi^{Rf*}\right), \tag{61}$$

$$\ln(R_t/R^*) = \Gamma_p \ln(\pi_t/\pi^*) + \Gamma_w \ln(\pi_t^w/\pi^{w*}), \tag{62}$$

$$\ln(R_t/R^*) = \Gamma_p \ln(\pi_t/\pi^*) + \Gamma_w \ln(\pi_t^w/\pi^{w*}) + \Gamma_f \ln\left(\pi_t^{Rf}/\pi^{Rf*}\right), \tag{63}$$

where $\pi_t^w \equiv W_t/W_{t-1}$, $\pi_t^{Rf} \equiv R_t^f/R_{t-1}^f$, are gross inflation rates for nominal wages and nominal office rents, respectively. Γ_p, Γ_w and Γ_f are policy parameters, and R^*, π^*, π^{w*},

π^{Rf*} are the target values for R_t, π_t, π_t^w, π_t^{Rf}, respectively. For simplicity, R^*, π^*, π^{w*} and π^{Rf*} are set at their respective *deterministic steady state values.* Following Canzoneri et al. (2005), we will refer to interest rate rules (59) to (61) as flexible price inflation targeting, flexible wage inflation targeting and flexible office rent inflation targeting rules, respectively, and interest rate rules (62) and (63) as "hybrid rule 1" and "hybrid rule 2".[13] We did not include output in the interest rate rules since Schmitt-Grohé and Uribe (2004a, 2006c, 2007) find that responding to output leads to large welfare costs in these types of models.

Following Schmitt-Grohé and Uribe (2006a,c, 2007), we impose two requirements on the interest rate rules, (59) to (63). First, the rule must yield a *locally unique* rational expectations equilibrium. Second, the rule must generate equilibrium dynamics for the nominal interest rate rule that respects the zero lower bound. Since we solve the model using perturbation methods which are not good at handling nonnegativity constraints, we follow Schmitt-Grohé and Uribe (2006a,c, 2007) and implement the second requirement by imposing the condition $2\text{std}(\ln R_t) < \ln(R)$, where $\text{std}(\ln R_t)$ is the standard deviation of $\ln R_t$, and $\ln(R)$ is the log of the steady state value of R_t.

Following Schmitt-Grohé and Uribe (2006a,c, 2007), we limit our attention to policy parameters, Γ_p, Γ_w and Γ_f, in the interval [0,3]. To compute the constrained optimal interest rate rule, we search numerically for the configuration of Γ_p, Γ_w and Γ_f that gives the highest welfare, with grid points from 0 to 3 and a step size of 0.1 for each of the policy parameters. We also compare the optimized "flexible" inflation targeting rules to the time-invariant Ramsey-optimal policy[14] and three types of "strict" inflation targeting rules: 1) strict price inflation targeting, $\pi_t = \pi^*$, 2) strict wage inflation targeting, $\pi_t^w = \pi^{w*}$ and 3) strict office rent inflation targeting, $\pi_t^{Rf} = \pi^{Rf*}$. The three "strict" inflation targeting rules can be seen

[13]We note, as Canzoneri et al. (2005) do, that the terminology of calling the interest rate rules (59) to (61) as "flexible inflation targeting" rules is not universal, as some researchers call a rule that reacts only to inflation as a "strict inflation targeting" rule and a rule that reacts to both inflation and output as a "flexible inflation targeting" rule.

[14]The Ramsey-optimal policy is computed using the Matlab toolbox developed by Andrew Levin in Levin et al. (2006).

as special cases of the "flexible" inflation targeting rules, (59) to (61), with $\Gamma_p = \infty$, $\Gamma_w = \infty$, and $\Gamma_f = \infty$, respectively.

Before we continue with the analysis, we make a note about the office rent inflation targeting rules. Schmitt-Grohé and Uribe (2004a, 2005, 2006a,b,c, 2007) argue that for a rule to qualify as a "simple, implementable" rule, the macroeconomic variable that the rule reacts to has to be easily observable. While we admit that data on office rents are harder to obtain compared to prices and wages, some institutions do collect office rent data. For instance, the Center for Real Estate at the MIT publishes on a regular basis a nationwide return series on commercial real estate that includes the rents. Some real estate companies also maintain quality adjusted rental indices, available for a fee. Therefore, the office rent inflation targeting rules that we propose are implementable in practice.

3 The welfare measure

The welfare measure, CV_0^a, that we use to evaluate a particular monetary policy regime, a, is the conditional expected lifetime utility of the representative household at time zero:

$$CV_0^a \equiv E_0 \sum_{t=0}^{\infty} \beta^t u(C_t^a, H_t^a). \tag{64}$$

We use the conditional expectation of lifetime utility instead of the unconditional expectation because unconditional expectation of lifetime utility does not take into consideration the welfare effects during the transition from an initial state to the stochastic steady state (Kim and Kim, 2003).[15] Following Schmitt-Grohé and Uribe (2006c, 2007), the expected lifetime utility is computed conditional on the initial state being the deterministic steady state. This has the advantage of ensuring that the economy starts from the same initial point, since for

[15] However, the results for this paper are very similar when the unconditional expectation of utility is used as the welfare measure.

a given set of parameter values, the steady states of this model are the same for all monetary policies considered in this paper.

We follow Lucas (1987) and report the welfare as the fraction, ζ^c, of steady state consumption that the household is willing to give up to be as well off under the steady state, as under a given monetary policy regime a, using CV_0^a as the welfare measure. Formally, ζ^c is given implicitly by:

$$\sum_{t=0}^{\infty} \beta^t \left(\frac{\left[(1-\zeta^c)\, C\right]^{1-\sigma} - 1}{1-\sigma} - \gamma \frac{H^{1+\xi}}{1+\xi} \right) = CV_0^a, \tag{65}$$

where variables without time subscripts denote the steady states of the corresponding variables. Higher values of ζ^c correspond to lower welfare.

4 Solution method and calibration

Since we use the expected utility of household as the welfare criterion, we solve the model by taking second-order Taylor approximations of the equations around a deterministic steady state, to capture the effects of uncertainty on the mean values of the variables (Kim and Kim, 2003; Schmitt-Grohé and Uribe, 2004b). We compute the second-order accurate solutions using the software package DYNARE (Juillard, 1996).

We calibrate the model to the US economy, with time unit being one quarter. The coefficient of relative risk aversion, σ, is set to 2, as is commonly assumed in the literature. The shares of business capital and offices, θ_1 and θ_2, are set to 0.1 and 0.15, respectively, following Gort et al. (1999) and Kan et al. (2004). The depreciation rates of business capital and offices, δ_k and δ_f, are both set to 0.025, which is the value commonly used for the depreciation rate of capital. This allows us to focus on the role of office rent rigidity.[16]

[16] In Gort et al. (1999), the depreciation rate of physical capital is set to 3%, while that of commercial real estate is 1% per quarter. We have conducted supplementary exercises to use that set of depreciation rates and find that our results are preserved. Those results are available upon request.

The subjective discount factor, β, is set to $1.04^{-1/4}$, following Schmitt-Grohé and Uribe (2004a, 2005, 2006b,c, 2007). The inverse of Frisch labor elasticity, ξ, is set to 1, following Christiano et al. (2005) and Schmitt-Grohé and Uribe (2006a). The preference parameter for labor in the utility function, γ, is calibrated so that the household spends 20% of their time working in the steady state. The adjustment cost parameters for business capital and offices, ϕ_k and ϕ_f, are both set to 15, so that the standard deviations of investments for business capital and offices are about 2 to 3 times the standard deviation of output. The elasticity of substitution across different varieties of goods, η_y, is set to 5 following Schmitt-Grohé and Uribe (2004a, 2006c, 2007). For simplicity, we also set the elasticity of substitution across different varieties of labor, η_h, and the elasticity of substitution across different varieties of offices, η_f, to 5. The fraction of firms not setting price optimally each quarter, α_y, and the fraction of labor markets not setting wages optimally each quarter, α_h, are both set to 0.75, following Canzoneri et al. (2005), which implies average price and wage durations of 4 quarters. We also set the fraction of office markets not setting office rents optimally each quarter, α_f, to 0.75, so that the three types of nominal rigidities have the same degrees of stickiness in the benchmark. As mentioned in the introduction, we believe that office rents are *at least* as rigid as prices and nominal wages. Setting the three types of nominal rigidities to have the same degrees of stickiness would allow us to compare their implications for the design of optimal monetary policy on an equal footing. However, we will also investigate the robustness of our results for both higher and lower degrees of stickiness for office rents. The degrees of indexation for prices, wages and office rents, χ_y, χ_h and χ_f are all set to 0 in the benchmark, following Amato and Laubach (2003) and Canzoneri et al. (2005). However, we will investigate the robustness of the results to alternative values of χ_y, χ_h and χ_f. Following Amato and Laubach (2003) and Canzoneri et al. (2005), we set the steady state gross inflation rate, π, to 1 in the benchmark, and investigate the robustness of the results to other values of π. Finally, we set the persistence and standard deviation of technology shocks, ρ^A and σ_{ε^A}, to 0.95 and 0.009, respectively, following Cho and Cooley (1995). Table 2 summarizes the benchmark parameterization.

(Table 2 about here)

5 The benchmark results

Table 3 shows the results under the benchmark parameterization. For the benchmark model, the Ramsey-optimal steady state net inflation rate is zero, which is the same as the steady state net inflation rate of the benchmark case. Given the structure of the model, this means that the steady state values of all variables under the Ramsey-optimal policy are the same as those for the interest rate rules for the benchmark case. It is interesting to note that under the Ramsey-optimal policy, the standard deviation of office rent inflation, at 0.35% per year, is less than half the standard deviations of price inflation and wage inflation (0.78% and 0.77% per year, respectively). This means that the Ramsey-optimal policy focuses more on stabilizing office rent inflation than on stabilizing price inflation and wage inflation. The lower standard deviation of office rent inflation translates into a lower mean resource cost of office rent dispersion, $\mathrm{E}(\hat{s}_{f,t})$, compared to the mean resource costs of price dispersion and wage dispersion, $\mathrm{E}(\hat{s}_{y,t})$ and $\mathrm{E}(\hat{s}_{h,t})$.

(Table 3 about here)

Turning to the interest rate rules, the flexible office rent inflation targeting rule is superior to the flexible price inflation targeting rule and the flexible wage inflation targeting rule. The optimized feedback coefficient on the office rent inflation in the flexible office rent inflation targeting rule takes the largest value allowed in our grid search, namely 3. Note that the optimized flexible office rent inflation targeting rule delivers a welfare level very close to that of the Ramsey-optimal policy, with a welfare difference of only 0.004% of steady state consumption. In addition, while increasing the feedback coefficient on the office rent inflation beyond 3 will increase the welfare, the improvement in welfare will be negligible, since even for the limiting case of the strict office rent inflation targeting rule, for which the feedback coefficient on the office rent inflation is infinite, the improvement in welfare is only 0.002% of steady state consumption.

Relative to the Ramsey-optimal policy, the optimized flexible price inflation targeting rule and flexible wage inflation targeting rule entail a welfare cost of 0.03 to 0.04% of steady state consumption. While this welfare cost is not large, it would be wrong to conclude that it does not matter which form of inflation targeting rules the government adopts. For instance, if the government adopts a strict price inflation targeting rule, the welfare cost relative to the Ramsey-optimal policy will be 0.3% of steady state consumption, which is large in the realm of policy evaluation at business cycles frequency.[17,18] Why does the strict price inflation targeting rule entail such a high welfare cost? As shown in Table 3, the strict price inflation targeting rule leads to very high standard deviations of office rent inflation and wage inflation, at 8.8% and 2.4% per year, respectively. This leads to high mean resource costs of office rent dispersion and wage dispersion, $\mathrm{E}(\hat{s}_{f,t})$ and $\mathrm{E}(\hat{s}_{h,t})$.

We can get some intuition of why strict price inflation targeting induces very high standard deviations of office rent inflation and wage inflation by looking at the impulse response functions and the relationship between price inflation Phillips curve and the marginal cost. Fig. 1 shows the impulse response functions of price inflation, wage inflation, office rent inflation and nominal interest rates in response to a 1% positive technology shock under the Ramsey policy as well as under the three types of strict inflation targeting rules. Under the benchmark parameterization, we can log-linearize and rearrange equations (37) and (45), to

[17] For comparison, the classic estimate of the welfare cost of business cycles in Lucas (1987) is 0.17% of steady state consumption, for a coefficient of risk aversion that is 10 times higher ($\sigma = 20$) than the one assumed in this paper. Canzoneri et al. (2005) also find a welfare cost of strict inflation targeting of 0.26 to 0.67% of steady state consumption in their NNS models with price and wage rigidities.

[18] It is also worthwhile to note that the strict price inflation targeting rule violates the zero bound condition on the nominal interest rate in this case.

obtain the familiar New Keynesian price inflation Phillips curve:

$$\widehat{\pi}_t = \beta E_t \widehat{\pi}_{t+1} + \frac{(1-\alpha_y)(1-\alpha_y \beta)}{\alpha_y} \widehat{mc}_t, \tag{66}$$

where a hat on a variable denotes the log deviation of a variable from its steady state value. Combining and log-linearizing equations (42) to (44), we can obtain an expression for the real marginal cost:

$$\widehat{mc}_t = \theta_1 \hat{r}_t^k + \theta_2 \hat{r}_t^f + (1-\theta_1-\theta_2)\hat{w}_t - \hat{A}_t. \tag{67}$$

We can see from equation (67) that a positive technology shock tends to decrease the real marginal cost. The downward pressure on the real marginal cost will then be passed on to price inflation through the price inflation Phillips curve, equation (66). If the government adopts a strict price inflation targeting rule, it will have to neutralize the downward pressure on the real marginal cost by raising the real business capital rent, r_t^k, the real office rent, r_t^f or the real wage, w_t. Given that the government stabilizes the price inflation, the real business capital rent, the real office rent and the real wage can be raised by lowering the nominal interest rate, so that the demand for goods, and hence the derived demand for the inputs increase. This will push up the nominal office capital rent and the nominal wage as shown in Fig. 1, which explains the high standard deviations of office rent inflation and wage inflation for the case of the strict price inflation targeting rule.

(Fig. 1 about here)

In contrast to the strict price inflation targeting rule, the strict wage inflation targeting rule and the strict office rent inflation targeting rule deliver much lower welfare cost. Similarly, we can obtain some intuition for this result from Fig. 1. As discussed above, in response to a positive technology shock, the price level tends to decrease because of the downward pressure on the marginal cost. On the other hand, the *real* wage and the *real* office rent tend to increase because the marginal productivity of labor hours and the marginal productivity of offices tend to increase. The upward pressures on the *real* wage and the *real* office rent partly offset the downward pressure on the price level, leading to a smaller downward pressure on the nominal wage inflation and the nominal office rent inflation. If the government adopts a strict office rent inflation targeting rule, it will have to decrease the nominal interest rate to counter the downward pressure on the nominal office rent inflation. However, as shown in Fig. 1, the decrease in the nominal interest rate would be smaller than the case of the strict price inflation targeting rule, since the downward pressure on the nominal office rent inflation is smaller than the downward pressure on the nominal price inflation. Therefore, the changes in the nominal wage inflation and the nominal price inflation for the case of the strict office rent inflation targeting rule would be smaller than the changes in the nominal wage inflation and the nominal office rent inflation for the case of the strict price inflation targeting rule. The smaller responses of the nominal wage inflation and the nominal price inflation translate to smaller resource costs of wage dispersion and price dispersion for the case of the strict office rent inflation targeting rule. A similar reasoning explains why the strict wage inflation targeting rule entails a smaller welfare cost compared to the case of the strict price inflation targeting rule.

It is interesting to note from Fig. 1 that the impulse responses for the case of the strict office rent inflation targeting rule are very close to the case of the Ramsey-optimal policy. This explains why the welfare level of the strict office rent inflation targeting rule is very close to the case of the Ramsey-optimal policy in Table 3. It also worthwhile to note that while the flexible wage inflation targeting rule is inferior to the flexible price inflation targeting rule in terms of welfare, the strict wage inflation targeting rule is better than the strict price inflation targeting rule. This means that if we expand the grid search for optimized coefficients beyond 3, the flexible wage inflation targeting rule would be able to beat the flexible price inflation targeting rule in terms of welfare.

Turning to the hybrid rules, Table 3 shows that the optimized hybrid rule 2, which reacts to the inflation rates of all three sticky nominal variables–goods prices, wages and office rents–deliver a welfare level almost exactly the same as that of the Ramsey optimal policy. The optimized hybrid rule 2 has feedback coefficients on the price inflation rate, the wage inflation rate and the office rent inflation of 3.0, 2.2 and 2.6, respectively. While the feedback coefficient on the price inflation rate in the optimized hybrid rule 2 is the largest, it is interesting to note that the standard deviation of office rent inflation is less than half the standard deviations of price and wage inflation. This means that the optimized hybrid rule 2 stabilizes the office rent inflation more than it stabilizes the price inflation rate and the wage inflation rate, similar to the case of the Ramsey-optimal policy.

Given the focus on stabilizing the office rent inflation, it is perhaps somewhat surprising that the optimized hybrid rule 1, which only reacts to the price inflation and the wage inflation, performs only marginally worse than the optimized hybrid rule 2, with a welfare difference of only 0.001% of steady state consumption. However, this result does not contradict the importance of stabilizing the office rent inflation. Note that under the optimized hybrid rule 1, the standard deviation of the office rent inflation is still lower than the standard deviations of price inflation and wage inflation. Hence, the optimized hybrid rule 1 delivers a level of welfare close to that of the optimized hybrid rule 2 because in this model, stabilizing *both* the price inflation and the wage inflation has the effect of stabilizing the office rent inflation as well. In contrast, the flexible price inflation targeting rule and the flexible wage inflation targeting rule, which only stabilize *either* the price inflation *or* the wage inflation, lead to higher standard deviations of office rent inflation and hence higher welfare costs.

We conclude from Table 3 that stabilizing the office rent inflation is an important focus of the optimal monetary policy when prices, wages and office rents are all rigid. In addition, while the optimized hybrid rule 2 is closest to the Ramsey-optimal policy in terms of welfare, we believe that the flexible office rent inflation targeting rule deserves serious consideration as a "simple, implementable" monetary policy rule, since it is only marginally worse than the optimized hybrid rule 2 in terms of welfare, with a welfare difference of only 0.004% of steady state consumption. The flexible office rent inflation targeting rule has the benefit that it is much easier to implement compared to the hybrid rule 2, since the government would only have to react to one variable instead of three. Reacting to fewer variables has the benefit of making the monetary policy more transparent and easier to understand for the public.

6 Robustness and sensitivity analysis

The previous section has established that under the benchmark parameterization, the office rent inflation targeting rule outperforms the traditional price inflation and wage inflation targeting rules. In this section, we investigate the robustness of our results to several "perturbations" of the benchmark case.

6.1 Indexation

In the benchmark model, we assume that the three nominal variables, prices, wages and office rents, have the same degrees of stickiness, and that none of them are indexed to past inflation. However, in the real world, these three nominal variables might not be symmetric. For instance, Levin et al. (2006) estimate that the degree of indexation for nominal wages is high, but the degree of indexation for goods prices is low. This type of asymmetry might have important implications for the design of the optimal monetary policy. In this subsection, we investigate the robustness of our results to the degrees of indexation.

In Table 4, we follow Schmitt-Grohé and Uribe (2005, 2006a,b) and assume that there is full indexation to the last period's price inflation for wages ($\chi_h = 1$) but no indexation for prices ($\chi_y = 0$). We also assume that there is full indexation for office rents ($\chi_f = 1$). All other parameters are fixed at their benchmark values. While there is no available empirical evidence on the degree of indexation for the office rents, we suspect that the degree of indexation for the office rents is closer to the wages, since as a factor of production, offices are more similar in nature to labor than to output.

(Table 4 about here)

With the exception of the welfare ranking between price inflation targeting and wage inflation targeting rules, the results in Table 4 are mostly similar to the benchmark results in Table 3. Under the Ramsey optimal policy,[19] the standard deviation of office rent inflation is still lower than the standard deviations of price inflation and wage inflation. This means that the focus of the Ramsey optimal policy continues to be stabilizing the office rent inflation. It is therefore not surprising that both the strict and flexible office rent inflation targeting rules still dominate the price inflation targeting and wage inflation targeting rules. The office rent inflation targeting rules also continue to be only marginally worse than the optimized hybrid rule 2 and the Ramsey-optimal policy, with welfare differences of less than 0.002% of steady state consumption.

One difference between the results in Table 4 and the benchmark results in Table 3 is that the strict wage inflation targeting rule now leads to a worse result than the strict price inflation targeting rule.[20] While the welfare cost of the strict price inflation targeting rule continues to be 0.35% of steady state consumption, the welfare cost of the strict wage inflation targeting rule jumps from 0.07% of steady state consumption in the benchmark to 0.46% for the current case. Comparing Table 3 and Table 4, the much higher welfare cost of the strict wage inflation targeting rule in Table 4 seems to stem from the higher

[19] The steady state net inflation rate for the Ramsey optimal policy is still zero in this version of the model.

[20] It is worthwhile to note that both the strict price inflation targeting rule and the strict wage inflation targeting rule violate the zero bound condition for the nominal interest rate.

standard deviation of office rent inflation, and hence the higher mean resource cost of office rent dispersion, $\mathrm{E}(\hat{s}_{f,t})$. Intuitively, when the nominal wages are indexed to the last period inflation, stabilizing the nominal wage inflation would require most of the adjustment to be shouldered by the nominal office rent inflation, making it much more volatile.[21]

6.2 Trend inflation

Following most existing studies in the literature, we assume that the steady state net inflation rate is zero in the benchmark model. However, this assumption might not be realistic since in the real world, long run inflation rates, which correspond to the steady state net inflation rate in the model, are not zero for most countries (Ascari, 2004). In a seminal paper, Ascari (2004) shows that with non-zero steady state net inflation and no indexation, the dynamics of a model with Calvo-style price adjustment can be very different from commonly assumed cases of either zero steady state net inflation or full indexation.[22] Ascari and Ropele (2007) further show that the steady state net inflation rate can alter the nature of optimal monetary policy. On the other hand, Schmitt-Grohé and Uribe (2004a, 2006c, 2007) find that the characteristics of optimal monetary policy in their model are robust to the steady state net inflation rate.[23] In this subsection, we investigate the robustness of our results to the steady state net inflation rate.

(Table 5 about here)

[21] We also consider a version of the model where only the office rents are indexed to past inflation, while there is no indexation for the prices and wages. The results are qualitatively the same as those in Table 4, except that the strict wage inflation targeting rule entails a much smaller welfare cost and hence is better than the strict price inflation targeting rule. These results are reported in an appendix available upon request.

[22] In earlier papers, King and Wolman (1996) and Ascari (1998), show that the steady state inflation rate affects the steady states of other variables.

[23] A difference between Ascari and Ropele (2007) and Schmitt-Grohé and Uribe (2004a, 2007) is that Ascari and Ropele use an arbitrary loss function as the welfare criterion while Schmitt-Grohé and Uribe use the utility of the representative household as the welfare criterion. It is not clear whether that explains the differences in their results.

In Table 5, we assume that the steady state net inflation rate is 4.2% per year ($\pi = 1.042^{1/4}$). This is the value used by Schmitt-Grohé and Uribe (2004a), and is consistent with the average US GDP deflator growth rate from 1960 to 1998. All other parameters are fixed at their benchmark values. As can be seen from the table, the results are similar to the benchmark, except that welfare costs are somewhat higher. We do not report the Ramsey results in this case because the Ramsey steady state net inflation rate is zero for this model, which makes the Ramsey policy not comparable with the results in this subsection. However, the standard deviation of office rent inflation continues to be lower than the standard deviations of price inflation and wage inflation for the optimized hybrid rule 2, which has the lowest welfare cost among the policy rules considered in Table 5. This means that the focus of the (constrained) optimal monetary policy is still on stabilizing the office rent inflation. In addition, the office rent inflation targeting rules (both the strict and flexible versions) continue to dominate the price inflation and wage inflation targeting rules. The flexible office rent inflation targeting rule is again only marginally worse than the hybrid rule 2, with a welfare difference of only 0.002% of steady state consumption. This shows that our results are robust to the steady state net inflation rate.[24]

6.3 Higher office rent rigidity

In the benchmark model, we assume that the average duration of office rent is 4 quarters, the same as the duration for prices and wages. However, as mentioned in the introduction, the lease terms on offices tend to be much longer than the duration of price and wage rigidities. For instance, based on micro-data, Sheehan (2006) finds that the mean term for an office rental contract is approximately 53 months. As argued in the introduction, while the existing studies have not looked at whether office rents are fixed during their entire lease terms, it is

[24] We also consider a version of the model where the steady state net inflation rate is -0.4% per year, which is the value used by Schmitt-Grohé and Uribe (2006a). The results are qualitatively similar to the benchmark and are reported in an appendix available upon request.

likely that office rents are rigid for *at least* one year. In this subsection, we investigate the robustness of our results to a higher degree of office rent rigidity.

(Table 6 about here)

We set $\alpha_f = 0.943$ in Table 6, so that the mean duration of office rent is approximately 53 months in the model, corresponding to an extreme assumption that office rents are fixed during their entire lease terms. All other parameters are fixed at their benchmark values. As can be seen from Table 6, the results are again qualitatively the same as the benchmark. Not surprisingly, with a higher degree of stickiness for the office rents, the Ramsey-optimal policy now stabilizes the office rent inflation even more, with the standard deviation of office rent inflation only 1/7 of the standard deviations of price inflation and wage inflation. The office rent inflation targeting rules (both the flexible and strict versions) continue to dominate the price inflation and wage inflation targeting rules in terms of welfare. However, the welfare differences between different monetary policies are now several times larger. The representative household will now have to be compensated by an equivalent of 0.13% to 0.34% of steady state consumption to induce them to switch from the optimized flexible office rent inflation targeting rule to the optimized flexible price inflation and wage inflation targeting rules. These welfare costs are substantial in the realm of business cycles. Even more remarkably, the strict price inflation targeting rule now entails a welfare cost of 3.47% of steady state consumption, which is *20 times* the estimate of the welfare cost of business cycles of Lucas (1987). In comparison, relative to the Ramey optimal policy, the optimized flexible office rent inflation targeting rule only entails a welfare cost of 0.02% of steady state consumption. Moreover, increasing the feedback coefficient on the office rent inflation in the flexible office rent inflation targeting rule beyond 3 would further reduce the welfare cost, since the strict office rent inflation targeting rule only entails a welfare cost of 0.001% of steady state consumption relative to the Ramsey-optimal policy. Hence, a robust conclusion from this subsection is that with a higher degree of stickiness for the office rent, the office rent inflation targeting rules that we propose become even more attractive alternatives to the more conventional price inflation and wage inflation targeting rules considered in the literature.

6.4 Flexible office rent

In the preceding subsection, we consider a case where the degree of office rent rigidity is much higher than the benchmark. In Table 7, we consider the polar opposite: a case where office rents are completely flexible. Since the rent of business capital is also flexible in our model, this case is similar to the usual assumption in the literature of complete rent flexibility. To do that, we set $a_f = 0$ in Table 7. All other parameters are fixed at their benchmark values.

(Table 7 about here)

As can be seen from Table 7, under the Ramsey-optimal policy, the standard deviation of office rent inflation is now higher than the standard deviations of price inflation and wage inflation. This means that the focus of the Ramsey-optimal policy is no longer on stabilizing the office rent inflation when the office rents are flexible. However, interestingly, both the strict and flexible versions of the office rent inflation targeting rules continue to dominate the price inflation and wage inflation targeting rules in terms of welfare, despite the fact that office rents are now completely flexible. The intuition of this result can be found in Table 7. Note that both the strict and flexible versions of the office rent inflation targeting rules deliver standard deviations of price inflation and wage inflation that are in between their price inflation and wage inflation targeting counterparts. For instance, the standard deviation of price inflation under the strict office rent inflation targeting rule (0.82%) is in between those of the strict price inflation targeting rule (0%) and the strict wage inflation targeting rule (1.28%). Similarly, the standard deviation of the wage inflation (0.86%) under the strict office rent inflation targeting rule is in between those of the strict price inflation targeting rule (2.40%) and the strict wage inflation targeting rule (0%). These patterns are confirmed in the impulse responses in Fig. 2, where the responses of price and wage inflation under the strict office rent inflation targeting rule are in between those of the strict price and wage inflation targeting rules. Hence, it appears that the office rent inflation targeting rules lead to higher welfare than the price and wage inflation targeting rules, even when the office rents are flexible, because the office rent inflation targeting rules stabilize *a weighted average* of price and wage inflation and hence *a weighted average* of the mean price and wage dispersion costs ($\mathrm{E}\hat{s}_{y,t}$ and $\mathrm{E}\hat{s}_{h,t}$). In contrast, price inflation targeting rules and wage inflation targeting rules only stabilize *either* price inflation *or* wage inflation at the expense of a higher standard deviation for the other variable, and hence lead to lower welfare. It is worthwhile to note that similar to the benchmark case, the flexible office rent inflation targeting rule is only marginally worse than the Ramsey-optimal policy, with a welfare difference of only 0.004% of steady state consumption. It is also worthwhile to note that the strict price inflation targeting rule continues to be the worst policy among those considered here, even though the welfare cost decreases to 0.13% of steady state consumption, which is much lower than the 0.35% for the benchmark, but still substantial in the realm of business cycle analysis.

(Fig. 2 about here)

One may wonder whether the result that even if office rents are flexible, the office rent inflation targeting rules continue to dominate the price and wage inflation targeting rules would continue to hold with only *either* price *or* wage rigidity. In an appendix available upon request, we show that if price rigidity is the only source of nominal stickiness, then price inflation targeting rules dominate the office rent inflation targeting rules. This confirms the results of existing studies that when the only source of nominal rigidity is price rigidity, stabilizing price inflation is optimal. However, we also find that the office rent inflation targeting rules will still be better than the wage inflation targeting rules when there is only price rigidity. Similarly, if wage rigidity is the only source of nominal stickiness, wage inflation targeting rules dominate the office rent inflation targeting rules, but the office rent inflation targeting rules will still be better than the price inflation targeting rules. Hence, we can conclude from these simulation exercises that as long as there is at least one source of nominal rigidity, the office rent inflation targeting rules are never the worst policy. More importantly, for the empirically more relevant cases of both prices and wages being rigid, the office rent inflation targeting rules will dominate the conventional price and wage inflation targeting rules, whether the office rents are rigid or not.[25,26]

7 Concluding remarks

The importance of nominal rigidity has long been recognized. As Barro and Grossman (1971, p.82) put it, "... the key to the Keynesian theory of income determination is the assumption that the vector of prices, wages, and interest rates does not move instantaneously from one full employment equilibrium position to another." However, the existing literature focuses only on the rigidity of nominal goods prices and wages. In this paper, we argue that nominal rents for at least one kind of capital, the offices, are *at least* as rigid as prices and nominal wages. We construct a closed economy NNS model with two types of capital, offices and business capital, to investigate how office rent rigidity affects the design of the optimal

[25] The findings that office rent inflation targeting rules dominate the price and wage inflation targeting rules, even when office rents are flexible, also raise the question of whether targeting the business capital rent inflation, which is flexible throughout this paper, will be better than targeting the office rent inflation when prices, wages and office rents are all rigid. In an appendix available upon request, we show that targeting the business capital rent inflation delivers welfare levels that are virtually indistinguishable from the office rent inflation targeting rules considered in this paper.

[26] We also consider a version of the model in which there are government spending shocks in addition to technology shocks. The results are qualitatively similar to the benchmark and are available in an appendix available upon request.

monetary policy.

We find that an interest rate rule that reacts only to the office rent inflation (which we call a "flexible office rent inflation targeting rule") achieves almost the same levels of welfare as the Ramsey-optimal policy in all the scenarios we consider. Moreover, as long as there are both nominal price and nominal wage rigidities, a flexible office rent inflation targeting rule dominates interest rate rules that react only to the price inflation *or* the wage inflation, regardless of whether the office rents are rigid. We conclude from these results that the flexible office rent inflation targeting rule deserves serious consideration as a simple optimal monetary policy rule that the central banks can consider to implement.

We conclude this paper by discussing the directions for future research. First, the potential superiority of the office rent inflation targeting rules demonstrated in this paper suggests that more research should be devoted to collecting data as well as understanding the behaviors and properties of the rents of various forms of capital. Second, it will be interesting to examine the performance of office rent inflation targeting rules in an open economy, with and without office rent rigidity. Finally, it will also be interesting to study how office rent inflation targeting rules interact with fiscal policy, especially with various kinds of nominal rigidity.

Table 1
Lease term for office in months

Percentiles	Lease term (months)		
5%	12		
10%	24		
25%	36		
50%	60		
75%	62		
90%	84	Observation	4494
95%	120	Mean	52.7
99%	126	Std. dev.	27.3

Notes: This table is reproduced from Table 8 of Sheehan (2006).

Table 2
Benchmark parameter values

Parameter	Description	Value
σ	Coefficient of relative risk aversion	2
θ_1	Business capital share	0.1
θ_2	Office share	0.15
δ_k	Depreciation rate of business capital	0.025
δ_f	Depreciation rate of office	0.025
β	Subjective discount factor	$1.04^{-1/4}$
ξ	Inverse of Frisch labor elasticity	1
γ	Preference parameter for labor in utility	57.45
ϕ_k	Business capital adjustment cost	15
ϕ_f	Office adjustment cost	15
η_y	Elasticity of substitution across different variety of goods	5
η_h	Elasticity of substitution across different variety of labor	5
η_f	Elasticity of substitution across different variety of office	5
α_y	Fraction of firms not setting price optimally each quarter	0.75
α_h	Fraction of labor markets not setting wage optimally each quarter	0.75
α_f	Fraction of office markets not setting rent optimally each quarter	0.75
χ_y	Degree of indexation for price	0
χ_h	Degree of indexation for wage	0
χ_f	Degree of indexation for office rent	0
π	Steady state gross inflation rate	1
ρ^A	Persistence of technology process	0.95
σ_{ε^A}	Standard deviation of technology shock	0.009

Table 3
Benchmark results

	Ramsey	Interest rate rules							
		Strict targeting			Flexible targeting			Hybrid targeting	
	policy	π_t	π_t^w	π_t^{Rf}	π_t	π_t^w	π_t^{Rf}	rule 1	rule 2
Γ_p	-	∞	-	-	2.2	-	-	3.0	3.0
Γ_w	-	-	∞	-	-	3.0	-	2.3	2.2
Γ_f	-	-	-	∞	-	-	3.0	-	2.6
ζ^c	0.041	0.346	0.069	0.043	0.071	0.086	0.045	0.042	0.041
Std(π_t)	0.78	0.00	1.28	0.82	0.86	1.44	0.99	0.81	0.80
Std(π_t^w)	0.77	2.41	0.00	0.86	1.31	0.25	0.66	0.75	0.75
Std(π_t^{Rf})	0.35	8.80	2.35	0.00	2.05	2.76	0.41	0.57	0.28
Std(R_t)	0.98	4.40*	0.65	0.96	1.89	0.76	1.22	0.93	1.02
E($\widehat{s}_{y,t}$)	0.01	0.00	0.03	0.01	0.01	0.04	0.02	0.01	0.01
E($\widehat{s}_{h,t}$)	0.01	0.11	0.00	0.01	0.03	0.00	0.01	0.01	0.01
E($\widehat{s}_{f,t}$)	0.00	1.45	0.10	0.00	0.08	0.14	0.00	0.01	0.00

Notes: (1) The interest rate rules are given by $\ln(R_t/R^*) = \Gamma_p \ln(\pi_t/\pi^*) + \Gamma_w \ln(\pi_t^w/\pi^{w*}) + \Gamma_f \ln(\pi_t^{Rf}/\pi^{Rf*})$. (2) In the optimized flexible targeting and hybrid targeting rules, Γ_p, Γ_w, Γ_f are restricted to lie in the interval [0, 3]. (3) ζ^c is the conditional welfare cost, expressed in percentage term. (4) For any variable x_t, Std(x_t) denote its unconditional standard deviation, measured in percent per year; E($\hat{x}_t$) denote the unconditional mean of the deviation of lnx_t from its steady state, measured in percentage term. (5) For the row of Std(R_t), a star beside a number indicates that the zero bound condition for the nominal interest rate is violated.

Table 4
Results for the case of full indexation for the wages and the office rents

	Ramsey	Interest rate rules							
		Strict targeting			Flexible targeting			Hybrid targeting	
	policy	π_t	π_t^w	π_t^{Rf}	π_t	π_t^w	π_t^{Rf}	rule 1	rule 2
Γ_p	-	∞	-	-	2.0	-	-	2.1	1.2
Γ_w	-	-	∞	-	-	2.2	-	1.3	0.0
Γ_f	-	-	-	∞	-	-	3.0	-	2.6
ζ^c	0.058	0.346	0.459	0.060	0.083	0.101	0.061	0.064	0.059
Std(π_t)	0.77	0.00	1.26	0.86	0.98	1.38	0.98	0.80	0.78
Std(π_t^w)	0.98	2.41	0.00	0.96	1.48	0.70	0.90	1.03	0.98
Std(π_t^{Rf})	0.54	8.80	10.79	0.00	2.41	2.67	0.29	0.96	0.25
Std(R_t)	0.95	4.40*	7.81*	0.69	1.96	1.54	0.88	1.11	0.75
E($\widehat{s}_{y,t}$)	0.01	0.00	0.03	0.01	0.02	0.04	0.02	0.01	0.01
E($\widehat{s}_{h,t}$)	0.03	0.11	0.03	0.03	0.04	0.02	0.03	0.04	0.03
E($\widehat{s}_{f,t}$)	0.01	1.45	2.45	0.01	0.07	0.19	0.01	0.03	0.01

Notes: (1) The interest rate rules are given by $\ln(R_t/R^*) = \Gamma_p \ln(\pi_t/\pi^*) + \Gamma_w \ln(\pi_t^w/\pi^{w*}) + \Gamma_f \ln(\pi_t^{Rf}/\pi^{Rf*})$. (2) In the optimized flexible targeting and hybrid targeting rules, Γ_p, Γ_w, Γ_f are restricted to lie in the interval [0, 3]. (3) ζ^c is the conditional welfare cost, expressed in percentage term. (4) For any variable x_t, Std(x_t) denote its unconditional standard deviation, measured in percent per year; E($\hat{x}_t$) denote the unconditional mean of the deviation of lnx_t from its steady state, measured in percentage term. (5) For the row of Std(R_t), a star beside a number indicates that the zero bound condition for the nominal interest rate is violated.

Table 5
Results for the case of 4.2% steady state net inflation rate

	Interest rate rules							
	Strict targeting			Flexible targeting			Hybrid targeting	
	π_t	π_t^w	π_t^{Rf}	π_t	π_t^w	π_t^{Rf}	rule 1	rule 2
Γ_p	∞	-	-	2.4	-	-	3.0	1.0
Γ_w	-	∞	-	-	3.0	-	1.8	0.0
Γ_f	-	-	∞	-	-	3.0	-	1.8
ζ^c	0.559	0.109	0.050	0.091	0.138	0.047	0.049	0.045
Std(π_t)	0.00	1.17	0.67	0.76	1.36	0.82	0.72	0.72
Std(π_t^w)	2.18	0.00	0.88	1.28	0.27	0.70	0.77	0.80
Std(π_t^{Rf})	10.27	3.22	0.00	2.56	3.63	0.39	0.52	0.32
Std(R_t)	3.88	0.64	0.91	1.83	0.80	1.17	1.01	1.11
E($\widehat{s}_{y,t}$)	0.00	0.04	0.01	0.01	0.06	0.02	0.01	0.01
E($\widehat{s}_{h,t}$)	0.14	0.00	0.02	0.04	0.00	0.01	0.02	0.02
E($\widehat{s}_{f,t}$)	2.76	0.27	0.00	0.17	0.35	0.00	0.01	0.00

Notes: (1) The interest rate rules are given by $\ln(R_t/R^*) = \Gamma_p \ln(\pi_t/\pi^*) + \Gamma_w \ln(\pi_t^w/\pi^{w*}) + \Gamma_f \ln(\pi_t^{Rf}/\pi^{Rf*})$. (2) In the optimized flexible targeting and hybrid targeting rules, Γ_p, Γ_w, Γ_f are restricted to lie in the interval [0, 3]. (3) ζ^c is the conditional welfare cost, expressed in percentage term. (4) For any variable x_t, Std(x_t) denote its unconditional standard deviation, measured in percent per year; E($\hat{x}_t$) denote the unconditional mean of the deviation of lnx_t from its steady state, measured in percentage term.

Table 6
Results for the case of a higher degree of office rent rigidity

		Interest rate rules							
	Ramsey	Strict targeting			Flexible targeting			Hybrid targeting	
	policy	π_t	π_t^w	π_t^{Rf}	π_t	π_t^w	π_t^{Rf}	rule 1	rule 2
Γ_p	-	∞	-	-	2.0	-	-	2.1	1.2
Γ_w	-	-	∞	-	-	2.2	-	1.3	0.0
Γ_f	-	-	-	∞	-	-	3.0	-	2.6
ζ^c	0.042	3.467	0.302	0.043	0.198	0.407	0.066	0.049	0.043
Std(π_t)	0.79	0.00	1.28	0.82	1.20	1.43	1.11	0.80	0.78
Std(π_t^w)	0.81	2.51	0.00	0.86	1.34	0.23	0.58	0.79	0.81
Std(π_t^{Rf})	0.11	7.97	2.16	0.00	1.55	2.54	0.55	0.39	0.19
Std(R_t)	0.97	7.43*	0.56	0.96	2.16*	0.68	1.65	0.90	1.00
E($\widehat{s}_{y,t}$)	0.01	0.00	0.03	0.01	0.03	0.04	0.02	0.01	0.01
E($\widehat{s}_{h,t}$)	0.01	0.12	0.00	0.01	0.03	0.00	0.01	0.01	0.01
E($\widehat{s}_{f,t}$)	0.01	28.80	2.12	0.00	1.09	2.92	0.14	0.07	0.02

Notes: (1) The interest rate rules are given by $\ln(R_t/R^*) = \Gamma_p \ln(\pi_t/\pi^*) + \Gamma_w \ln(\pi_t^w/\pi^{w*}) + \Gamma_f \ln(\pi_t^{Rf}/\pi^{Rf*})$. (2) In the optimized flexible targeting and hybrid targeting rules, Γ_p, Γ_w, Γ_f are restricted to lie in the interval [0, 3]. (3) ζ^c is the conditional welfare cost, expressed in percentage term. (4) For any variable x_t, Std(x_t) denote its unconditional standard deviation, measured in percent per year; E($\hat{x}_t$) denote the unconditional mean of the deviation of lnx_t from its steady state, measured in percentage term. (5) For the row of Std(R_t), a star beside a number indicates that the zero bound condition for the nominal interest rate is violated.

Table 7
Results for the case of flexible office rent

		Interest rate rules							
	Ramsey	Strict targeting			Flexible targeting			Hybrid targeting	
	policy	π_t	π_t^w	π_t^{Rf}	π_t	π_t^w	π_t^{Rf}	rule 1	rule 2
Γ_p	-	∞	-	-	2.6	-	-	3.0	3.0
Γ_w	-	-	∞	-	-	3.0	-	2.7	2.3
Γ_f	-	-	-	∞	-	-	3.0	-	1.9
ζ^c	0.040	0.129	0.054	0.043	0.058	0.065	0.044	0.041	0.041
Std(π_t)	0.78	0.00	1.28	0.82	0.72	1.45	0.98	0.85	0.81
Std(π_t^w)	0.74	2.40	0.00	0.86	1.36	0.25	0.66	0.69	0.74
Std(π_t^{Rf})	0.85	8.86	2.37	0.00	2.36	2.78	0.40	0.70	0.32
Std(R_t)	0.71	4.22*	0.66	0.96	1.87	0.76	1.21	0.89	1.02
E($\widehat{s}_{y,t}$)	0.01	0.00	0.03	0.01	0.01	0.04	0.02	0.01	0.01
E($\widehat{s}_{h,t}$)	0.01	0.11	0.00	0.01	0.03	0.00	0.01	0.01	0.01
E($\widehat{s}_{f,t}$)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes: (1) The interest rate rules are given by $\ln(R_t/R^*) = \Gamma_p \ln(\pi_t/\pi^*) + \Gamma_w \ln(\pi_t^w/\pi^{w*}) + \Gamma_f \ln(\pi_t^{Rf}/\pi^{Rf*})$. (2) In the optimized flexible targeting and hybrid targeting rules, Γ_p, Γ_w, Γ_f are restricted to lie in the interval [0, 3]. (3) ζ^c is the conditional welfare cost, expressed in percentage term. (4) For any variable x_t, Std(x_t) denote its unconditional standard deviation, measured in percent per year; E($\hat{x}_t$) denote the unconditional mean of the deviation of lnx_t from its steady state, measured in percentage term. (5) For the row of Std(R_t), a star beside a number indicates that the zero bound condition for the nominal interest rate is violated.

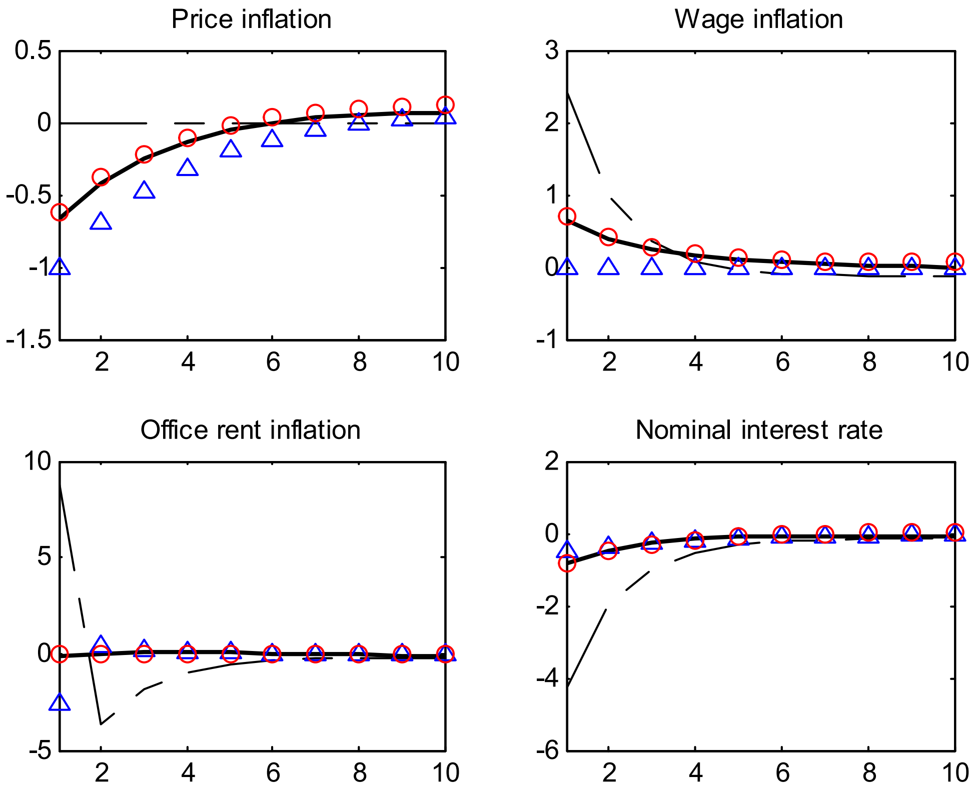

Fig 1. Impulse responses to a 1% positive technology shock under different monetary policies for the benchmark model.

Legend: Dark lines: Ramsey-optimal policy; dotted lines: strict price inflation targeting; triangles: strict wage inflation targeting; circles: strict office rent inflation targeting.
Notes: The responses are in annual percentage terms.

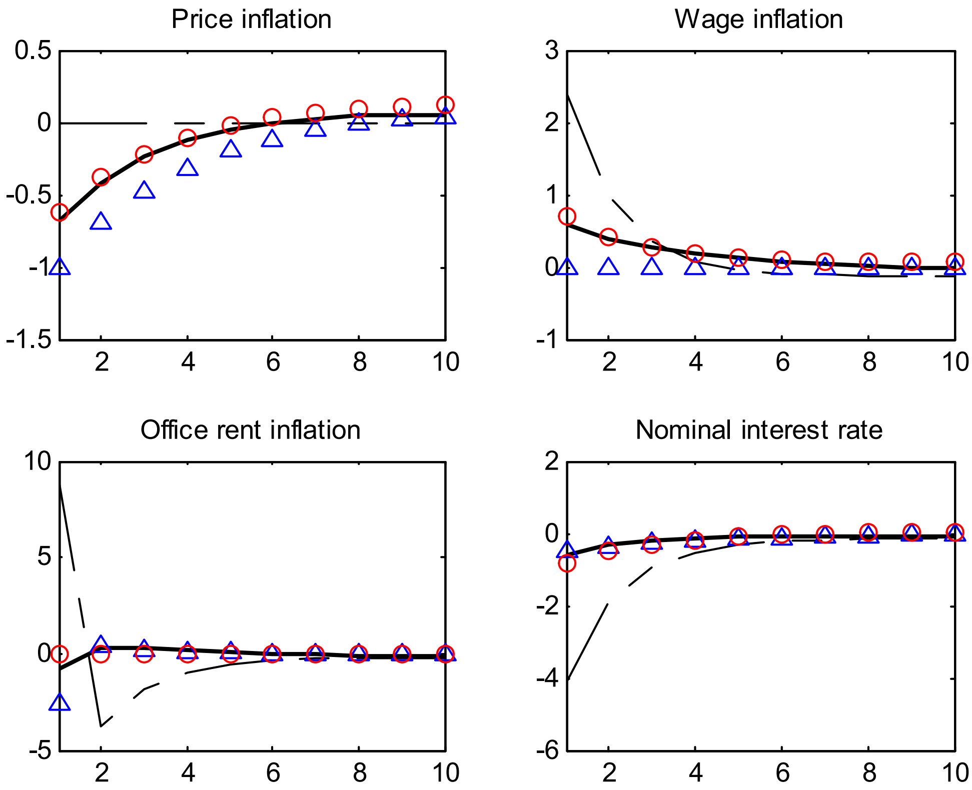

Fig 2. Impulse responses to a 1% positive technology shock under different monetary policies for the case of flexible office rents.

Legend: Dark lines: Ramsey-optimal policy; dotted lines: strict price inflation targeting; triangles: strict wage inflation targeting; circles: strict office rent inflation targeting. Notes: The responses are in annual percentage terms.

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