Optimal Monetary Policy and Downward Nominal Wage Rigidity in Frictional Labor Markets.

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24 September 2009

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First Draft- February 2009

This Draft- October 2010

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Abstract

Empirical evidence suggests that nominal wages in the U.S. are downwardly rigid. This paper studies the optimal long-run inflation rate in a labor search and matching framework under the presence of Downward Nominal Wage Rigidity (DNWR). In this environment, optimal monetary policy targets a positive inflation rate; the annual long-run inflation rate for the U.S. is around 2 percent. Positive inflation "greases the wheels" of the labor market by facilitating real wage adjustments, and hence it eases job creation and prevents excessive increase in unemployment following recessionary shocks. These findings are related to standard Ramsey theory of "wedge smoothing"; by following a positive-inflation policy under sticky prices, the monetary authority manages to reduce the volatility and the size of the intertemporal distortion significantly. The intertemporal wedge is completely smoothed when prices are fully flexible. Since the optimal long-run inflation rate predicted by this study is considerably higher than in otherwise neoclassical labor markets, the nature of the labor market in which DNWR is studied can be relevant for policy recommendations.

Keywords: Downward Nominal Wage Rigidity, Optimal Monetary Policy; Long Run Inflation Rate; Grease Inflation Rate; Labor Market Frictions; Labor Search and Matching; Intertemporal Wedge Smoothing.

JEL Classification: E31, E32, E52, E58.

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1 Introduction

This paper studies optimal monetary policy in the presence of Downward Nominal Wage Rigidity (DNWR) within a labor search and matching model.[1] When nominal wages are downwardly rigid, optimal monetary policy sets a strictly positive inflation rate, of about 2 percent annually, in the long run. A strictly positive long-run inflation rate is driven by precautionary considerations in the expectations of adverse shocks. Positive inflation allows for downward real wage adjustments (thus "greasing the wheels" of the labor market) which eases job creation and limit the increase in unemployment following adverse shocks.

The results of the paper are related to standard Ramsey theory of smoothing distortions (or "wedges") over time. A virtually constant distortion across periods is the main insight of Barro (1979), in a partial equilibrium framework, and Chari, Christiano and Kehoe (1991) in a quantitative general equilibrium model, among others. Recently, Arseneau and Chugh (2010) have developed intertemporal and static notions of efficiency in general equilibrium models with labor search and matching frictions. They show that the intertemporal wedge should indeed be smoothed, but, contrarily to the cornerstone result of tax smoothing in the Ramsey literature, that occurs through volatility in labor income taxes. In this paper, optimal monetary policy, which calls for a positive inflation rate due to DNWR, reduces the size and the volatility of the intertemporal wedge when prices are sticky. This fact suggests that with both intertemporal and nominal distortions in place, the monetary authority cannot completely smooth both distortions simultaneously. When prices are fully flexible, however, monetary policy keeps the intertemporal wedge virtually constant over the business cycle by varying the inflation rate. Therefore, the volatility and the size of the intertemporal wedge are both falling in the inflation rate as the degree of price rigidity varies.

The results under zero-inflation policy at all dates and states are significantly different. In this case, the volatility of the intertemporal wedge is substantially higher; the wedge absorbs the shock. Similar results are obtained for labor market variables; the combination of DNWR and fully stable prices limit the decline in real wages considerably, thus generating unemployment increases and job creation declines far beyond their responses under a positive inflation target.

[1] DNWR means not only that wage increases are more likely than wage cuts, but also that the distribution of wage changes is not symmetric. Nominal wages tend to increase in good times but they do not tend to fall proportionally in bad times, thus generating an asymmetric distribution of wage changes. Note that the fact that wage increases are more common than wage cuts by itself is insufficient evidence for the presence of DNWR; a preponderance wage increases may reflect long-term productivity growth or steady state (positive) inflation.

The paper is motivated by several recent empirical studies indicating DNWR. Some of the most notable recent evidence on DNWR is the comprehensive work of the International Wage Flexibility Project (IWFP), reviewed in Dickens *et al.*(2007a, 2007b). Their findings indicate asymmetry in the distribution of nominal wage changes in 16 OECD countries, with the U.S. being among the countries with very high degrees of DNWR. Gottschalk (2005) shows that after correcting for measurement errors that typically appear in wages reported in surveys, only about 5% of workers experienced wage cuts during a course of a year while working for the same employer. Card and Hyslop (1997) show a spike at zero in the distribution of nominal wage changes, indicating DNWR. The size of this spike is highly correlated with inflation; it significantly increased in the mid 1980's when inflation rates fell relative to the 1970's. In addition, their analysis reveals that, on average, real wages would have been lower by around 1% per year in the mid 1980's had nominal wages not been downwardly rigid. Using large financial corporation wage and salary data, Altonji and Devereux (2000) find that only 0.5% of salaried workers had salary cuts and 2.5% of hourly workers had wage reductions.

The idea that positive inflation may be needed to "grease the wheels" of the labor market dates back at least to Tobin (1972). Following negative shocks that call for a fall in the real wage, Tobin (1972) suggests that setting a positive inflation rate, on one hand, and stabilizing nominal wages, on the other, would facilitate real wage adjustment in the presence of DNWR. Tobin's idea has gained more attention in recent years for two reasons. First, inflation rates have become very low in the last two decades. Clearly, DNWR is more relevant in low inflation environments and during recessions. Second, central banks around the world do in fact target positive inflation rates, either explicitly or implicitly. DNWR may create a precautionary motive for positive inflation: since the timing of (negative) shocks is not fully predictable, the monetary authority keeps the inflation rate positive on average in order to "ensure" against negative shocks once they materialize.

This study allows for staggered price setting, downwardly rigid nominal wages, and search and matching frictions in the labor market, the latter being consistent with positive unemployment in equilibrium. To model DNWR, I follow Kim and Ruge-Murcia (2009) and Fahr and Smets (2008) by using the *Linex* wage adjustment cost function. This function delivers higher costs in case of wage cuts relative to wage increases. To see the significance of this setup, consider the response of an economy to an adverse productivity shock. If inflation is high, then downward rigidity in nominal wages cannot prevent real wage drops, and hence inflation mitigates the potential increase in unemployment. In case of low inflation rates, however, DNWR may translate into Downward Real Wage Rigidity (DRWR). In this case, if the monetary authority seeks to keeps prices stable (due to a direct cost of adjusting prices), downward rigidity in real wages implies higher unemployment than in the absence of DNWR. If the monetary authority instead chooses to stabilize employment, it inflates in order to achieve the desired cut in real wages. That is, the inflation rate needed 'to grease the wheels' of the economy is higher than it would be if nominal wages were not downwardly rigid. In short, the presence of labor market frictions may magnify the need for grease inflation if policy makers are trying to keep unemployment low, or it may create excessive unemployment when attempting to keep prices close to full stability.

The current study contributes to some recent literature that studies the optimal inflation rate in the presence of DNWR. In a frictionless labor market environment, Kim and Ruge-Murcia (2009) show that the optimal annual grease inflation in the U.S. is positive (around 0.4 percent). Unlike the current study, they estimate the model's parameters based on some Taylor-type rule. In an earlier version of their paper (Kim and Ruge-Murcia, 2007), the monetary authority chooses allocations to maximize households' welfare, but without assuming any Taylor-type rule. In that case, the optimal annual grease inflation is found to be 1.2 percent. Fagan and Messina (2009) introduce asymmetric menu costs for wage setting and show that the optimal inflation rate for the U.S. ranges between 2 percent and 5 percent when nominal wages are downwardly rigid. The optimal inflation rate in their model depends on the dataset used to measure the degree of DNWR. The optimal long run inflation rate found in the current paper is thus more in line with the results of Fagan and Messina (2009).

The fact that the inflation rate suggested by the current study is significantly higher than in Kim and Ruge-Murcia (2007, 2009), despite the use of a similar proxy for DNWR, suggests that structure of the labor market in which DNWR is studied may matter for policy recommendations. Since the discussion is over the long-run inflation rate, these differences are economically significant. In addition, the average inflation rate in the United States has been around 2.5 percent in the last two decades. Therefore, the current study may also be seen as one that suggests a theoretical ground for targeting an inflation rate of around 2 percent.

The remainder of this paper proceeds as follows. Section 2 outlines the search and matching model economy with DNWR. Section 3 discusses the search-based efficient allocations and the intertemporal wedge. Section 4 describes the calibration methodology and the parameterization of the model. Section 5 presents the results regarding the optimal inflation rate. Impulse Response functions following productivity shocks are presented in section 6. Section 7 examines the performance of two extreme policies, full price stability and full employment stability, relative to optimal policy. Section 8 concludes.

2 The Model Economy

Apart from the monetary authority, the economy is populated by households and monopolistically-competitive firms that produce differentiated products. Hiring labor by firms is subject to search and matching frictions. Following literature, the model embeds the search and matching framework of Pissarides (2000), which has become the main framework within which optimal monetary policy is studied in the presence of labor market frictions.[2] Each firm faces asymmetric adjustment cost for nominal wages that implies higher costs of cutting nominal wages relative to increasing nominal wages by the same magnitude. Changing prices by each firm is subject to a direct resource cost. The model allows for variations in total hours along both the extensive and the intensive margin.

2.1 Households

The economy is populated by a representative household which consists of family members of measure one. At each date t a household member can be in either of two states: employed or unemployed and searching for a job. Employed individuals are of measure n_t and the unemployed are of measure u_t, where $u_t = 1 - n_t$, as conventional in the literature.

Following the assumptions of consumption insurance in Merz (1995) and Andolfatto (1996), all family members in this household have the same consumption. The disutility of work is assumed to be the same for all employed individuals and the value of non-work is the same for all unemployed individuals. Given these assumptions, the household's problem is to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[u(c_t) - n_t v(h_t) \right], \tag{1}$$

where $\beta < 1$ is the standard subjective discount factor, E_0 is the expectation operator , c_t is the composite consumption index, h_t denotes hours per worker, $u(\cdot)$ is the period utility function from consumption and $v(h_t)$ is the period disutility function from supplying labor. These functions satisfy the Inada conditions and the usual properties: $\frac{\partial u(\cdot)}{\partial c} > 0$, $\frac{\partial^2 u(\cdot)}{\partial c^2} < 0$, $\frac{\partial v(\cdot)}{\partial h} > 0$ and $\frac{\partial^2 v(\cdot)}{\partial h^2} > 0$.

[2] Note that my model assumes no idiosyncratic shocks, unlike, for example, Mortensen and Pissarides (1994).

As standard in New Keynesian models, consumption (c_t) is a Dixit-Stiglitz aggregator of differentiated products (c_{jt}) produced by monopolistically-competitive firms,

$$c_t = \left(\int_0^1 c_{jt}^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{2}$$

where $\varepsilon > 1$ is the elasticity of substitution between two varieties of final goods. In line with standard Dixit-Stiglitz based NK models, the optimal allocation of expenditures on each variety is given by

$$c_{jt} = \left(\frac{P_{jt}}{P_t} \right)^{-\varepsilon} c_t, \tag{3}$$

where $P_t = \left(\int_0^1 P_{jt}^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}}$ is the Dixit-Stiglitz price index that results from cost minimization.

Maximization is subject to the sequence of budget constraints of the form

$$c_t + \frac{B_t}{P_t} = \frac{n_t h_t W_t}{P_t} + (1-n_t)b + \frac{R_{t-1}B_{t-1}}{P_t} + \frac{T_t}{P_t} + \frac{\Theta_t}{P_t}, \tag{4}$$

where b stands for unemployment benefits, B_t denotes nominal bonds, W_t is the nominal wage, R_t is the nominal gross interest rate on bonds, P_t is the aggregate price level, T_t are net transfers and Θ_t stands for profits from the ownership of firms.

Household's choices of consumption and bond holdings yield the following optimality condition:

$$u_{ct} = \beta R_t E_t \left(\frac{u_{ct+1}}{\pi_{t+1}} \right), \tag{5}$$

in which ($\pi_t = P_t / P_{t-1}$) denotes the gross price inflation rate.

2.2 Firms in the Labor Market

There is a continuum of measure one of monopolistically-competitive firms. Each firm *j* hires labor as the only input and produces differentiated products using the following linear technology

$$y_{jt} = z_t n_{jt} f(h_{jt}), \tag{6}$$

with z_t denoting aggregate productivity, which is common to all firms, n_{jt} is employment at time *t* in firm *j*, and h_{jt} is hours per worker supplied by each worker at the firm. The pricing of a firm is subject to a quadratic adjustment cost as in Rotemberg (1982), expressed in units of the final output.

Hiring workers by each firm is subject to search and matching costs. Each period firms post vacancies and they meet unemployed workers searching for jobs. Nominal wages and hours per worker are determined in a Nash bargaining process between workers and firms as will be outlined later. As noted by Krause and Lubik (2007), the assumption of quadratic adjustment cost and symmetry among firms allows for integrating price decisions and employment decisions in the same firm.

Each firm faces an asymmetric wage adjustment cost function that involves a higher cost in case of a nominal wage cut compared to a nominal wage increase.[3] In particular, following Kim and Ruge-Murcia (2009), the real wage adjustment cost per employed individual is given by the following *Linex* function:

$$\Phi_{jt}^{W} = \frac{\phi}{\psi^{2}}\left(\exp[-\psi(\frac{W_{jt}}{W_{jt-1}} - 1)] + \psi(\frac{W_{jt}}{W_{jt-1}} - 1) - 1 \right). \tag{7}$$

For any positive value of ψ, the cost of cutting nominal wages by a specific amount is higher than the cost of increasing wages by the same amount. Also, as ψ approaches zero, this function approaches the quadratic adjustment cost and hence enables comparison with the symmetric adjustment function. In the other extreme, as ψ approaches infinity, this function becomes L-shaped implying that nominal wages cannot fall. Naturally, this parameter will have special significance in my analyses, particularly regarding the optimal long-run inflation rate.

Posting a vacancy *v* entails a cost of γ for a firm. Matches between vacant jobs and unemployed individuals are governed by a constant return-to-scale-matching function of the form [4]

$$m(v_t, u_t) = \sigma_m u_t^{\zeta} v_t^{1-\zeta}, \tag{8}$$

where σ_m is a scaling parameter that reflects the efficiency of the matching process. Labor market tightness is measured as

[3] The assumption that firms pay the adjustment costs of wages is without loss of generality. In a model where workers unilaterally set their wages, they will naturally pay the wage adjustment cost. In this model however, the wage rate is determined through bargaining between firms and workers. Hence, households do not have all the bargaining power and they therefore are not wage setters in the typical manner. In this case, it is less clear who should pay the cost of adjusting wages. I assume that firms entail these costs without loss of generality. Note that this assumption has no effect on the economy-wide resource constraint.

[4] The variable *u* measures the number of unemployed individuals at time *t*. The corresponding unemployment rate is given by $ur_t = 1-(1-u_t)(1-\rho)^{-1}$.

$$\theta_t = \frac{v_t}{u_t}. \tag{9}$$

The probability of the firm to fill a job (i.e. the job filling rate) is given by $q(\theta_t) = \frac{m(v_t, u_t)}{v_t}$. Using the properties of the matching function it can be written as

$$q(\theta_t) = \sigma_m \theta_t^{-\zeta} \ , \tag{10}$$

which is decreasing in labor market tightness. Intuitively, the higher the ratio of vacancies to unemployment, the lower the probability for a specific vacancy to be filled. Similarly, the job finding rate (i.e. $p(\theta_t) = \frac{m(v_t, u_t)}{u_t}$) can be written as

$$p(\theta_t) = \sigma_m \theta_t^{1-\zeta} \ , \tag{11}$$

and hence it increases in tighter labor markets. Finally, employment in each firm evolves according the following law of motion:

$$n_{jt+1} = (1-\rho)\left(n_{jt} + m(v_{jt}, u_t)\right), \tag{12}$$

with ρ denoting the separation rate from a match. Using the expression for the job-filling rate and the law if motion of employment can also be written as

$$n_{jt+1} = (1-\rho)(n_{jt} + v_{jt} q(\theta_t)). \tag{13}$$

In this formulation, I assume that a match formed at time *t* starts to produce at time *t+1* given that it survived exogenous separations.

Each firm chooses its price vacancies and employment for next period to maximize the expected presented discounted stream of profits given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \left\{ \frac{P_{jt}}{P_t} y_{jt} - n_{jt} w_{jt} h_{jt} - \gamma v_{jt} - \frac{\phi}{\psi^2} \left(\exp[-\psi(\frac{W_{jt}}{W_{jt-1}} - 1)] + \psi(\frac{W_{jt}}{W_{jt-1}} - 1) - 1 \right) n_{jt} - \frac{\phi^p}{2} \left(\frac{P_{jt}}{P_{jt-1}} - 1 \right) y_t \right\}, \tag{14}$$

subject to the sequence of laws of motion of employment, and the :

$$n_{jt+1} = (1-\rho)(n_{jt} + v_{jt} q(\theta_t)), \tag{15}$$

and the downward-sloping demand function for its product

$$z_t n_{jt} f(h_{jt}) = \left[\frac{P_{jt}}{P_t} \right]^{-\varepsilon} y_t \ . \tag{16}$$

Households are assumed to own the firms, and hence firms discount next period's profits by the stochastic discount factor of households (i.e. $\beta \frac{\lambda_{t+1}}{\lambda_t}$), where λ_t is the Lagrange multiplier on the households budget constraint.

Let μ_{jt} be the Lagrange multiplier associated with the employment law of motion (equation 15), and φ_{jt} be the Lagrange multiplier associated with the output constraint (equation 16). The multiplier φ_{jt} measures the contribution of one additional unit of output to the revenue of the firm, and it equals, in equilibrium, the real marginal cost of the firm. Imposing symmetry across firms, and assuming that all workers supply the same number of hours (h), the first-order conditions with respect to n_{jt+1} and v_{jt} read, respectively, as follows:

$$\mu_t \lambda_t = \beta E_t \left\{ \lambda_{t+1} \left[\varphi_{t+1} z_{t+1} f(h_{t+1}) - w_{t+1} h_{t+1} - \frac{\phi}{\psi^2} \left(\exp[-\psi(\frac{W_{t+1}}{W_t} - 1)] + \psi(\frac{W_{t+1}}{W_t} - 1) - 1 \right) + (1-\rho)\mu_{t+1} \right] \right\}, \tag{17}$$

and,

$$-\gamma + (1-\rho) q(\theta_t) \mu_t = 0 \ . \tag{18}$$

Combining conditions (15) and (16) and the fact that $\lambda_t = u_{ct}$, give the Job Creation (*JC*) condition:

$$\frac{\gamma}{q(\theta_t)} = \beta(1-\rho) E_t \left\{ \left(\frac{u_{ct+1}}{u_{ct}} \right) \left[\varphi_{t+1} z_{t+1} f(h_{t+1}) - w_{t+1} h_{t+1} - \frac{\phi}{\psi^2} \left(\exp[-\psi(\pi^w_{t+1} - 1)] + \psi(\pi^w_{t+1} - 1) - 1 \right) + \frac{\gamma}{q(\theta_{t+1})} \right] \right\}, \tag{19}$$

where ($w_t = \frac{W_t}{P_t}$) is the real wage. Thus, in equilibrium, the firm equates the vacancy-creation cost to the discounted expected value of profits from the match. As the term in brackets makes clear, the flow profit to a firm from a match equals output net of wage payments and costs of adjusting wages.[5] This condition is also referred to as the free-entry condition for posting vacancies.

[5] To see this clearly, one may write this condition in the following way

$$\gamma = q(\theta_t)(1-\rho) E_t \left\{ \left(\beta \frac{u_{ct+1}}{u_{ct}} \right) \left[\varphi_{t+1} z_{t+1} f(h_{t+1}) - w_{t+1} h_{t+1} - \frac{\phi}{\psi^2} \left(\exp[-\psi(\pi^w_{t+1} - 1)] + \psi(\pi^w_{t+1} - 1) - 1 \right) + \frac{\gamma}{q(\theta_{t+1})} \right] \right\}$$

The LHS is the cost of posting a vacancy. The RHS shows the discounted expected value of profits from a given match. The firm enjoys profits from this match in case of being filled (which occurs with probability $q(\theta_t)$) and surviving exogenous separation (which occurs with probability $(1-\rho)$). We can use the last term in the RHS to iterate forward and hence get the expected PDV of profits. In short, this equation equates the cost of posting a vacancy (the LHS) to the (expected) benefit of posting that vacancy.

By taking first order condition with respect to the price P_{jt} and assuming symmetry among firms (since they all set the same price in equilibrium), we get the following price Philips curve (see Appendix D):

$$1-\phi^{p}(\pi_{t}-1)\pi_{t}+\beta\phi^{p}E_{t}\left[\left(\frac{u_{ct+1}}{u_{ct}}\right)(\pi_{t+1}-1)\pi_{t+1}\frac{y_{t+1}}{y_{t}}\right]=\varepsilon(1-\varphi_{t})\,. \tag{20}$$

This equation shows that the current inflation rate is an implicit function of the expected inflation rate and the real marginal cost. This equation collapses in the case of fully flexible prices ($\phi^{p}=0$) or fully stable prices ($\pi_{t}=1$ for all *t*) to the familiar condition, $\varphi_{t}=\frac{\varepsilon-1}{\varepsilon}$, the inverse of the gross price markup.

2.3 Nash Bargaining

As is typical in the literature, wage payments and hours per employed individual are determined by Nash bargaining between firms and individuals. I follow Thomas (2008) and Arseneau and Chugh (2008) among others by assuming that bargaining is over nominal wages W_{t} rather than real wages w_{t} (as typically has been the assumption). This assumption allows focusing on nominal wages, which are the subject of this study. To have a good notion for downward wage rigidity one should focus on the determination of nominal wages, since if bargaining is over real wages, downward real wage rigidity will have no implications for monetary policy. As discussed in Fahr and Smets (2008), Downward Real Wage Rigidity means than nominal wages are indexed to inflation, which in case of full indexation, implies a zero greasing inflation rate. Put differently, the fact that real wages cannot fall following negative shocks regardless of the inflation rate makes grease inflation irrelevant. Given that deviation from price stability is costly, optimal policy will fully stabilize prices. This renders the discussion here less relevant.

Firms and workers split the surplus of a match according to their bargaining power. The asset value for an employed worker from a job is given by

$$V_{t}^{W}=W_{t}h_{t}-\frac{P_{t}v(h_{t})}{u_{ct}}+\beta E_{t}\left[\left(\frac{u_{ct+1}}{u_{ct}}\right)\left(\frac{P_{t}}{P_{t+1}}\right)\left((1-\rho)V_{t+1}^{W}+\rho V_{t}^{U}\right)\right], \tag{21}$$

where the disutility from work is expressed in terms of the marginal utility of consumption (and hence is equal to the marginal rate of substitution between consumption and labor). Therefore, the asset value for an employed individual is the difference between his current wage payment and the disutility from labor together with the discounted continuation value of staying employed or becoming unemployed next period, with the two events taking place with probabilities $(1-\rho)$ and ρ, respectively.

Similarly, the asset value for an unemployed worker can be expressed as

$$V_t^U = P_t b + \beta E_t \left[\left(\frac{u_{ct+1}}{u_{ct}} \right) \left(\frac{P_t}{P_{t+1}} \right) \left(\theta_t q(\theta_t)(1-\rho) V_{t+1}^W + (1 - \theta_t q(\theta_t)(1-\rho)) V_{t+1}^U \right) \right], \tag{22}$$

which equals unemployment benefits plus the continuation value. The latter is the weighted sum of the values of staying unemployed next period (which occurs with probability $(1-\theta_t q(\theta_t)(1-\rho))$) and becoming employed (which occurs with probability $\theta_t q(\theta_t)(1-\rho)$).

Finally, the value of a filled job for a firm (after suppressing the index *j*) is

$$V_t^V = \varphi_t z_t f(h_t) - W_t h_t - \frac{\phi}{\psi^2} \left(\exp[-\psi(\frac{W_t}{W_{t-1}} - 1)] + \psi(\frac{W_t}{W_{t-1}} - 1) - 1 \right) P_t + \beta E_t \left[\left(\frac{u_{ct+1}}{u_{ct}} \right) \left(\frac{P_t}{P_{t+1}} \right) (1-\rho) V_{t+1}^V \right]. \tag{23}$$

Therefore, the value of each match equals the flow value of its product net of wage payments and wage adjustment costs plus the continuation value of that match in case of surviving separation.

The Nash bargaining problem is to choose W_t and h_t to maximize

$$(V_t^W - V_t^U)^{\eta} V_t^{V\,1-\eta}, \tag{24}$$

where η denotes the bargaining power of workers (and their share in the match surplus). In equilibrium, the value of posting a vacancy is zero and hence the threat point of firms is set to zero in the above formulation. The first-order condition with respect to W_t reads

$$\eta (V_t^W - V_t^U)^{\eta-1} \left(\frac{\partial V_t^W}{\partial W_t} - \frac{\partial V_t^U}{\partial W_t} \right) V_t^{V\,1-\eta} + (1-\eta) V_t^{V\,-\eta} \frac{\partial V_t^V}{\partial W_t} (V_t^W - V_t^U)^{\eta} = 0. \tag{25}$$

Denoting the *effective* bargaining power of workers by ω_t, the first-order condition with respect to W_t can be re-written as

$$(V_t^W - V_t^U) = \frac{\omega_t}{(1-\omega_t)} V_t^V, \tag{26}$$

with $\omega_t = \dfrac{\eta}{\eta + (1-\eta)\dfrac{\Delta_t^F}{\Delta_t^W}}$, $\Delta_t^W = -\left(\dfrac{\partial V_t^W}{\partial W_t} - \dfrac{\partial V_t^U}{\partial W_t} \right)$ and $\Delta_t^F = \dfrac{\partial V_t^V}{\partial W_t}$.

If nominal wages are costless to adjust, ω_t will be exactly equal to η.[6] The wage adjustment cost drives a wedge between the effective and the ex-ante bargaining powers. Also, since the parameter ψ

[6] To see this, notice that if ϕ=0, then $\dfrac{\partial V_t^W}{\partial W_t} = h_t$ and $\dfrac{\partial V_t^V}{\partial W_t} = -h_t$. Hence, $\dfrac{\Delta_t^F}{\Delta_t^W}$ =1, and $\omega_t = \eta$.

appears in the expression for Δ_t^F, the presence of DNWR plays here a role in determining the effective bargaining power of workers. As ψ increases, the cost of increasing wages becomes very low and hence the effective bargaining power approaches its ex-ante value, η.

Combining the job creation condition (19) with the asset value for the firm from a match (23) gives

$$V_t^V = \varphi_t z_t f(h_t) - W_t h_t - \frac{\phi}{\psi^2}\left(\exp[-\psi(\pi_t^w - 1)] + \psi(\pi_t^w - 1) - 1\right)P_t + \frac{\gamma P_t}{q(\theta_t)} \quad . \tag{27}$$

It is evident that the more downwardly rigid nominal wages, the lower the value to a firm from a given match. Also, substituting the expression for V_t^V yields the equation characterizing the *real* wage setting:

$$\frac{\omega_t}{1-\omega_t}\left[\varphi_t z_t f(h_t) - w_t h_t - \frac{\phi}{\psi^2}\left(\exp[-\psi(\pi_t^w - 1)] + \psi(\pi_t^w - 1) - 1\right) + \frac{\gamma}{q(\theta_t)}\right] = w_t h_t - \frac{v(h_t)}{u_{ct}} - b + E_t\left[\frac{\omega_{t+1}}{1-\omega_{t+1}}\left(\frac{\gamma}{q(\theta_t)} - \gamma\theta_t\right)\right]. \tag{28}$$

The current wage is affected by the cost of adjusting nominal wages, the outside option (*b*), the disutility from labor and the continuation value of the worker being employed.[7]

Finally, the equation characterizing the determination of hours per employed individual is given by

$$\frac{\Gamma_t}{1-\Gamma_t}\left[\varphi_t z_t f(h_t) - w_t h_t - \frac{\phi}{\psi^2}\left(\exp[-\psi(\pi_t^w - 1)] + \psi(\pi_t^w - 1) - 1\right) + \frac{\gamma}{q(\theta_t)}\right] = w_t h_t - \frac{v(h_t)}{u_{ct}} - b + E_t\left[\frac{\Gamma_{t+1}}{1-\Gamma_{t+1}}\left(\frac{\gamma}{q(\theta_t)} - \gamma\theta_t\right)\right]. \tag{29}$$

where $\Gamma_t = \dfrac{\eta}{\eta + (1-\eta)\dfrac{\delta_t^F}{\delta_t^W}}$, $\delta_t^W = -\dfrac{\partial V_t^W / \partial h_t}{P_t}$ and $\delta_t^F = \dfrac{\partial V_t^V / \partial h_t}{P_t}$.

To find expression (29), the FOC with respect to *h* was expressed as $(V_t^W - V_t^U) = \dfrac{\Gamma_t}{(1-\Gamma_t)} V_t^V$.

[7] Condition (29) can also be written in the following way:

$$w_t h_t = \omega_t\left[\varphi_t z_t f(h_t) - \frac{\phi}{\psi^2}\left(\exp[-\psi(\pi_t^w - 1)] + \psi(\pi_t^w - 1) - 1\right) + \frac{\gamma}{q(\theta_t)}\right] + (1-\omega_t)\left[\frac{v(h_t)}{u_{ct}} + b\right] + E_t\left[\frac{\omega_{t+1}(1-\omega_t)}{1-\omega_{t+1}}\left(\gamma\theta_t - \frac{\gamma}{q(\theta_t)}\right)\right]$$

Therefore, the wage paid to a worker is a weighted average of the value of his output (net of wage adjustment costs), the value of his outside options, the disutility of work, and the present discounted value of his expected gain from search. In the absence of wage adjustment costs, this expression collapses to the more familiar equation

$$w_t h_t = \eta\left[\varphi_t z_t f(h_t) + \gamma\theta_t\right] + (1-\eta)\left[\frac{v(h_t)}{u_{ct}} + b\right].$$

Hence, the real wage of a worker is equal to the share η of the revenue and saving of hiring costs, and he is compensated by the share $(1-\eta)$ of the disutility from supplying work and the foregone unemployment benefits.

2.4 The Private Sector Equilibrium

The equilibrium conditions of the private sector are the consumption Euler equation (5) describing intertemporal choices, the law of motion for employment (13), the job creation condition (19), the price Philips curve (20), the wage setting equation (28), the hours determination equation (29) , the resource constraint of the economy given by

$$n_t z_t h_t^{\alpha} - c_t - \gamma\theta_t u_t - \frac{\phi}{\psi^2}\left(\exp[-\psi(\pi_t^w - 1)] + \psi(\pi_t^w - 1) - 1\right)n_t - \frac{\phi^p}{2}\left(\pi_t - 1\right)^2 n_t z_t h_t^{\alpha} = 0\,, \tag{30}$$

the constraint on unemployment

$$u_t = 1 - n_t\,, \tag{31}$$

and finally, the identity describing real wage growth

$$\frac{w_t}{w_{t-1}} = \frac{\pi_t^w}{\pi_t}\,, \tag{32}$$

which is typically introduced in sticky price and sticky nominal wage models. As explained in Chugh (2006) and Arseneau and Chugh (2008), this identity does *not* hold trivially in the case of rigid nominal wages and hence it should be added to the equilibrium conditions of the private sector.[8]

Note that in condition (30), I substitute for v_t using the expression for labor market tightness ($v_t = \theta_t u_t$).

Definition 1: Given the exogenous processes $\{R_t, z_t\}$, the private sector equilibrium is a sequence of allocations $\{c_t, h_t, n_t, u_t, \theta_t, \varphi_t, w_t, \pi_t, \pi_t^w\}$ that satisfy the equilibrium conditions (5), (13), (19), (20) and (28)-(32).

2.5 The Optimal Monetary Policy Problem

The monetary authority in this economy seeks to maximize the household's welfare subject to the resource constraint and the first order conditions of individuals and firms (see Appendix C for the full optimal monetary policy problem). Formally, given the exogenous process for technology z_t, the monetary authority chooses $\{c_t, h_t, n_t, u_t, \theta_t, \varphi_t, w_t, \pi_t, \pi_t^w\}$ in order to maximize (1) subject to (13), (19), (20) and (28)-(32).

[8] This constraint also appears in the study of Erceg, Henderson and Levin (2000).

3 Search Efficiency and the Intertemporal Wedge

In the basic Ramsey theory of public finance, the planner aims at smoothing distortions (or "wedges") over the business cycle. This is the main insight of the partial-equilibrium "tax-smoothing" result of Barro (1979). Chari,Christano and Kehoe (1991) show that this result is carried over to a general equilibrium framework. Judd (1985) and Chamley (1986) established that the optimal capital income tax in the steady state is zero and that there are no intertemporal distortions. Albanesi and Armenter (2007) generalize this idea and show that, in the deterministic steady state of a general class of optimal policy problems, it is optimal to achieve zero intertemporal distortion. More recently, Arseneau and Chugh (2010) have shown, within a labor search and matching model, that the Ramsey planner aims indeed at smoothing intertemporal wedges, but that is not mapped into tax smoothing. In the current paper, the only "tax" available to the Ramsey planner is the inflation rate. Hence, I also examine whether the notion of "wedge smoothing" applies to the current setup, and if does, how that is mapped into smoothing the inflation rate.

The derivations, presented in Appendix A, give to the following definitions

$$IMRS = \frac{u_{ct}}{\beta u_{ct+1}}, \tag{33}$$

and,

$$IMRT = \frac{(1-\rho)\left[z_{t+1}h_{t+1}^{\alpha} - \frac{v(h_{t+1})}{u_{ct+1}} + \frac{\gamma\left[1-m_u(1-n_{t+1},v_{t+1})\right]}{m_v(1-n_{t+1},v_{t+1})}\right]}{\frac{\gamma}{m_v(1-n_t,v_t)}}. \tag{34}$$

These definitions are borrowed from the recent work of Arseneau and Chugh (2010). *IMRS* is the intertemporal marginal rate of substitution between consumption choices across periods (put differently, the ratio of marginal utilities at time t and time $t+1$). *IMRT* stands for the intertemporal marginal rate of transformation, and it measures the increase in consumption at time $t+1$ as a result of a forgone one unit of consumption at time t.

As shown in Appendix A, efficiency requires *IMRT=IMRS* for all t. The efficiency condition can also be written as

$$1 = (1-\rho)E_t\left\{\left(\frac{\beta u_{ct+1}}{u_{ct}}\right)\left[\frac{z_{t+1}f(h_{t+1}) - \frac{v(h_{t+1})}{u_{ct+1}} + \frac{\gamma\left[1-m_u(1-n_{t+1},v_{t+1})\right]}{m_v(1-n_{t+1},v_{t+1})}}{\frac{\gamma}{m_v(1-n_t,v_t)}}\right]\right\}, \tag{35}$$

In the decentralized economy, the equivalent condition to (36) is given by

$$1=(1-\rho)E_t\left\{\left(\frac{\beta u_{ct+1}}{u_{ct}}\right)\left[\frac{(1-\omega_{t+1})}{(1-\zeta)}\left(\frac{\varphi_{t+1}z_{t+1}f(h_{t+1})-\dfrac{v(h_{t+1})}{u_{ct+1}}-\Phi^W_{t+1}-b+\dfrac{\gamma(1-\zeta)}{m_v(1-n_{t+1},v_{t+1})}\left(1+E_{t+1}\left[\dfrac{\omega_{t+2}}{1-\omega_{t+2}}\left(1-\dfrac{m_u(1-n_{t+1},v_{t+1})}{\zeta}\right)\right]\right)}{\dfrac{\gamma}{m_v(1-n_t,v_t)}}\right)\right]\right\}. \quad (36)$$

Comparing the square brackets in condition (35) with the square brackets in condition (36) implicitly defines the "intertemporal wedge". By comparing (35) with (36), sufficient conditions for efficiency are: nominal wages are fully flexible or fully stabilized (i.e. Φ^W_{t+1}=0, and hence $\omega_{t+1}=\eta$), the Hosios condition holds ($\zeta=\eta$), the unemployment benefits are zero (b=0), and no monopolistic power in the final-good sector (which implies φ_{t+1}=1). See Appendix B for further details.

The fact that the adjustment cost of nominal wages appears in the term defining the intertemporal wedge is of special significance. When nominal wages are not fully flexible (or not fully stabilized), they induce a *direct* effect on the intertemporal wedge. But, nominal wage rigidity has also an *indirect* effect on the intertemporal wedge, which happens through the deviation of the effective bargaining power of workers (ω_t) from its ex-ante value (η). This is well reflected in the last term of the numerator of condition (36). The fact that nominal wages are downwardly rigid only magnifies the two effects in periods of downturn. Hence, "smoothing" nominal wages is one way to smooth the wedge over time. Setting a positive inflation rate lead, at least partially, to smoothing nominal wages, and hence the intertemporal wedge. This can be easily seen by substituting for the real marginal cost (φ_t) using the Phillips curve.

4 Calibration

The first subsection discusses the parameterization of the model, and the second subsection presents some discussion about the calibration methodology applied in this study.

4.1 Parameterization:

There are two groups of parameters. The values of the first group will be set to conventional values in the existing literature. The second group of parameters, namely the adjustment cost parameters of prices and nominal wages and the measure for DNWR, are obtained to match certain data moments. I follow this approach since most parameters of the model are commonly used in existing literature and hence there is no necessity to estimate them. The adjustment costs parameters will thus be consistent with commonly-used values for other parameters.

I assume the following period utility function:

$$u(c_t, h_t, n_t) = \frac{c_t^{1-\sigma}}{1-\sigma} - n_t \chi \frac{h_t^{1+\vartheta}}{1+\vartheta}$$

I set the parameter σ to 2. The parameter ϑ is set at 2, implying a labor supply elasticity of 0.5.[9] I then calibrate χ such that the SS level of hours is 0.3, as is conventional in literature. I assume a time unit of a quarter and hence the discount factor β is set to 0.99.

Output per worker has diminishing returns in hours per worker, as follows:

$$f(h_t) = h_t^{\alpha},$$

where α is set to 2/3 implying a labor share of output of about 67%, in line with literature.

The matching process between vacancies and unemployed individuals is governed by the following constant return-to-scale function:

$$m(v_t, u_t) = \sigma_m u_t^{\zeta} v_t^{1-\zeta}$$

The parameter ζ measures the elasticity of matches with respect to unemployment and is set here to 0.40 in line with several studies (e.g. Arseneau and Chugh, 2008 and Faia, 2008). The parameter σ_m measures the efficiency of the matching process and is calibrated in my benchmark case to be 0.658. This value has been calibrated assuming that the probability to fill a vacancy is 0.7 and the probability to find a job is 0.6, as conventional in the literature. The implied steady state value of labor market tightness

[9] Previous studies considered elasticity between 0.1 and 1, corresponding to values of 10 and 1 for ϑ, respectively. I choose here an intermediate value for the elasticity of hours.

is 6/7. I therefore calibrate the value of posting vacancies γ to match this SS level of θ; the value obtained for γ is 0.413. Also, following Shimer (2005) and Arseneau and Chugh (2008), among others, I set the quarterly separation rate ρ at 0.10.

As is standard in literature, I assume that the Hosios (1990) condition holds and hence that the Nash bargaining power of workers is equal to the contribution of an unemployed individual to the match (i.e. $\eta = \zeta$). As shown in Hosios (1990), this condition guarantees the efficiency of the matching process.

Productivity is governed by the following AR(1) process:

$$ln(z_t) = \rho_z ln(z_{t-1}) + \varepsilon_t$$

ρ_z is set to 0.95 in line with previous literature. The innovation term ε_t is normally distributed with zero mean and a standard deviation of $\sigma_\varepsilon = 0.007$, as typically assumed in the literature.

The parameters governing the adjustment cost functions of prices and nominal wages (i.e. ϕ^p, ϕ and ψ) are estimated using the Simulated Method of Moments (SMM). In my baseline calibration, I choose parameters to match the standard deviations of consumption, wage inflation, price inflation, real wages, hours per employed individual and employment. However, as a robustness check, I also redo my work using other groups of moments to match. The resulting parameter estimates in my baseline calibration are $\phi^p = 26.9$, $\phi = 87.3$ and $\psi = 2567.3$.

4.2 Computational Solution

The main purpose of this paper is to address optimal monetary policy in the presence of asymmetries in the adjustment of nominal wages. Linearization cannot account for this asymmetry since, by construction, it eliminates the asymmetries of the model. Therefore, I need to apply second-order approximations for the monetary authority's equilibrium conditions. A second-order approximation allows for the unconditional mean of the variable in the "stochastic steady state" to be different from its deterministic steady state value. In particular, it allows the unconditional mean to be affected by the size of the underlying shock. Finally, I apply the second order approximation procedure of Schmitt-Grohe and Uribe (2004).

5 The Optimal Inflation Rate

This section presents the main findings regarding optimal monetary policy under search and matching frictions in the presence of downward rigidity in nominal wages. I first discuss the deterministic steady state and then turn to the dynamics of the model.

5.1 The Optimal Inflation Rate in the Deterministic Steady State

The deterministic steady state of the model is invariant to the degrees of price stickiness, wage stickiness and asymmetry in the adjustment of nominal wages. In the absence of shocks, inflation is not beneficial, and due to the direct cost of deviation from complete price stability, the monetary authority completely stabilizes prices (and nominal wages) in the deterministic steady state. This fact is unrelated to whether wages are flexible or rigid.

5.2 The Optimal Long-Run Inflation Rate

In this subsection I discuss the dynamics of the model. As a benchmark, I first examine the case with fully flexible wages (i.e. $\phi = 0$). When wages are costless to adjust, and prices are rigid, optimal monetary policy fully stabilizes prices (Panel I, Table 1). In this case, all the adjustment of real wages occurs through instantaneous adjustment of nominal wages. When nominal wages are rigid, but the adjustment cost function is symmetric ($\phi > 0, \psi = 0$), the optimal grease inflation rate is zero (Panel I, Table 1): in the latter case, the symmetry of the wage adjustment cost eliminates the precautionary motive for inflation.[10]

This is the main result of the paper is reported in panel III. When nominal wages are downwardly rigid ($\psi > 0$), optimal monetary policy deviates from full price stability in the long run; the optimal annual long-run inflation rate is slightly above 2 percents. This is an important result for, at least, two reasons. First, the optimal inflation rate is significantly higher than in a model with neoclassical labor markets (as for example in the work of Kim and Ruge-Murcia, 2007). This fact suggests that the nature of

[10] In both cases, the 95 percent confidence intervals include the zero. The confidence interval for the case with fully flexible wages is (-0.0057, 0.0020), and the confidence interval for the case with a symmetric adjustment cost of wages is (-0.0193, 0.0221). Hence, the hypothesis that the optimal inflation rate is zero cannot be rejected in either of the two cases.

the labor market in which DNWR is studied can be important for policy recommendations. Second, the optimal inflation rate suggested by this paper is only about half a percent lower than the average annual inflation rate in the U.S. during the last two decades. Hence, the current environment can be seen as one that justifies an inflation rate of more than 2 percents as observed in U.S. data.

	I		II		III	
	Fully Flexible Wages ($\phi = 0$)		Rigid Wages, Symmetric Adjustment Cost ($\psi = 0$)		Rigid Wages, Asymmetric Adjustment Cost ($\psi = 2567.3$)	
x	μ_x	σ_x	μ_x	σ_x	μ_x	σ_x
π	-0.0018	0.0385	0.0014	0.5605	2.1505	3.7184
π^w	0.0190	2.0317	0.0003	0.1362	2.1204	2.9052
y	0.3782	1.1189	0.3782	1.1718	0.3801	1.3507
c	0.3229	1.0238	0.3229	0.9287	0.3237	1.1530
h	0.3000	0.2596	0.3000	0.3021	0.3009	0.4702
w	1.1178	2.7432	1.1176	1.9594	1.1132	2.4304
u	0.1563	1.7040	0.1563	1.9656	0.1583	3.6871
ur	0.0626	1.8933	0.0626	2.1840	0.0648	4.0968
v	0.1339	1.7194	0.1339	1.9965	0.1361	4.1440
θ	0.8576	2.9148	0.8576	3.3697	0.8859	7.4962

Table 1: Simulated moments- Second order approximation. $\phi = 87.3$ and $\phi^p = 26.9$.
μ_x - the mean of the variable. σ_x - the standard deviation of the variable (in percents).
Price inflation and wage inflation are presented in *annualized* terms.

The model does well in accounting for the volatilities of key macroeconomic aggregates (e.g. output, consumption and hours per worker). The standard deviations of labor market variables (i.e. vacancies, unemployment, unemployment rate, and labor market tightness) are well below their values in actual U.S. data. The failure of the labor search and matching model to account for the true volatilities of labor market aggregates is well known in the literature since the seminal paper of Shimer (2005). The model, however, manages to capture the volatilities of *v* and *u relative* to the volatility of θ as shown in data. The model also captures the relative volatilities of *v* and *ur*, and the level of the unemployment rate (around 6.25 percent, in line with the literature). Finally, the model with DNWR better accounts for the volatilities of these three variables compared to the model with fully flexible nominal wages and the model with symmetric adjustment cost of nominal wages.

5.3 Discussion- The Optimal Inflation Rate and Intertemporal Wedge Smoothing

The strictly positive long-run inflation rate is due to precautionary behavior by the monetary authority. Since the timing (and magnitude) of adverse shocks is not fully predictable, a positive inflation rate over time allows for real wage adjustments when nominal wages are downwardly rigid, and hence it eases job creation and limits the increase in unemployment.

This result can also be rationalized by considering basic Ramsey theory of "wedge smoothing". As discussed in section (3), DNWR acts, directly and indirectly, towards generating a wedge between the intertemporal marginal rate of substitution and the intertemporal marginal rate of transformation, thus positioning the economy away from the efficient state. Therefore, the Ramsey planner acts in a manner that aims at closing this source of distortion, at least partially. This happens through stabilizing nominal wages to the maximum possible extent. Holding a positive inflation rate over time serves in achieving the real wage adjustments with less nominal wage adjustments and hence lower distortion.

The role of inflation in smoothing the intertemporal wedge is well documented in Figure 1. The figure shows the standard deviation of the intertemporal wedge for various optimal inflation rates obtained under different values of the price rigidity parameter (ϕ^p). Clearly, the volatility of the intertemporal wedge is falling with the optimal annual long-run inflation rate. This finding supports the earlier expectations that positive inflation helps in reducing the volatility of the intertemporal wedge.

In the standard Ramsey theory, the intertemporal wedge should be completely smoothed over time. This is not the result here for the following reasons. First, the monetary authority does not have enough set of instruments to completely and simultaneously stabilize all distortions, including the intertemporal distortion, over the business cycle. Hence, the monetary authority chooses to spread the distortions across all margins. This is a well-know result in the literature (Dupor, 2002). Second, deviations from zero inflation rate are costly, and hence the monetary authority trades-off between stabilizing the inflation rate and stabilizing the intertemporal wedge through stabilization of nominal wages. The convexity of the adjustment costs of nominal wages and prices makes it not optimal to fully stabilize one of the two variables and allow for the other variable to vary.

It is interesting to contrast these findings with the results under a policy that commits to a zero-inflation rate at all dates. Figure 3 shows that standard deviation of the intertemporal wedge for various degrees of DNWR (ψ) under both optimal policy and a zero-inflation policy. The standard deviation of the wedge is considerably smaller under a positive inflation rate policy than under a zero-inflation policy, particularly for the relevant values of ψ (which are around 2600 given a benchmark calibration value of 2567.3). Moreover, as the degree of DNWR increases, the difference between the standard deviations becomes bigger. Hence, inflation has a more significant role in smoothing the intertemporal wedge as nominal wages become more downwardly rigid.

The intertemporal wedge is almost entirely smoothed when prices are fully flexible (Figure 4).[11] In this case, the monetary authority has more room for policy actions that stabilize the intertemporal wedge. Put differently, the monetary authority faces less trade-offs in conducting policy. Indeed, with fully flexible prices, the intertemporal wedge is essentially smoothed over time, regardless of the degree of asymmetry in the adjustment cost of nominal wages.

Figure 5 also helps to shed light on this result. The figure is drawn under the assumption that the monetary authority commits to a certain inflation target at all dates and states. The figure shows the mean levels and the standard deviations of unemployment rate and vacancies as a function of the inflation target (ranging between zero and 3 percents). The unemployment rate drops significantly in the range between zero inflation rate and about 2 percents. On the other hand, vacancy posting increases significantly in this range. The standard deviations of both variables fall considerably as the target increases in this range. Basically, two important conclusions can be obtained from this figure. First, inflation is more important in "greasing" the wheels of the labor market for low inflation rates, as expected. In addition, the trade-off between inflation and unemployment is more significant for lower inflation rates. Second, the marginal "benefit" from increasing the inflation rate approaches zero as we move beyond, approximately, 2 percents. This observation just supports an optimal inflation rate of about 2 percents.

5.4 The Optimal Inflation Rate- Sensitivity Analyses

The goal of this subsection is to check whether the main result of this paper, an inflation rate of about 2 percents holds once other empirical moments to match are chosen. The results are shown in Table 2. In general, I choose here two different cases: in the first, I allow for only 3 moments to match (and so the number of moments equals the number of parameters). In the second, the number of moments exceeds the number of parameters.

The results show that the long run inflation rate is usually around 2 percents, ranging from about 1.80 percents to about 2.44 percents. The higher inflation rate in the latter case (where the standard deviation of labor market tightness is targeted) is due to the fact that in order to account for the high standard deviation of labor market tightness, a higher ψ is needed. This in turn leads to a higher inflation rate.

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[11] In fact, for inflation to be determinate, prices in the current setup cannot be fully flexible. Hence, "fully flexible" prices refer to the case where the adjustment cost of price is set to 10^{-5}.

	I	II	III	IV	V
Moments	The Standard Deviations of c, n and π^w	The Standard Deviations of c, h, w, π^w and n	The Standard Deviations of c, w, θ	The Standard Deviations of c, w, π^w and θ	The Standard Deviations of c, π^w and θ
π	1.8016	1.8706	2.2324	2.3757	2.4372
π^w	1.8256	1.8645	2.1971	2.4201	2.4359

Table 2: Simulated moments- Second order approximation. Each entry shows the *annualized* mean of the variable.

In general, the analyses in this subsection confirm my earlier result; the optimal long run inflation rate in a model with DNWR and labor market frictions is about 2 percent. In addition, all cases considered the optimal grease inflation rate is considerably higher than the optimal grease inflation rate in Kim and Ruge-Murcia (2007, 2009). Hence, the nature of the labor market in which DNWR is imbedded seems to matter for policy analysis.

6 Impulse Responses

This section describes, under optimal policy, the behavior of the economy following negative and positive productivity shocks of the same magnitude (the size of the shock is one standard deviation of the shock to TFP). Figure 6 shows the behavior of the main variables of interest under the presence of DNWR. These variables display asymmetry in their responses to negative and positive shocks, particularity those of big sizes (a big shock is defined here as of two standard deviation size).

Nominal wages do not almost fall following a negative shock, but they increase considerably following a positive shock. The asymmetry in the response of nominal wages is more significant the bigger the size of the shock. Price inflation increases considerably following a negative shock, but it falls only slightly below its SS level following a positive shock of the same magnitude. This finding confirms the role of inflation in greasing the wheels of the labor market following negative shocks when nominal wages are downwardly rigid.

Unemployment displays asymmetry in the response to productivity shocks and it is more persistent following big negative shocks. The asymmetry in unemployment is less than the asymmetry in price inflation and wage inflation. This fact is due to less asymmetry in the behavior of real wages: since prices and nominal wages almost complement each other following shocks, the fall in real wages following a negative shock (which almost entirely occurs through the increase in prices) is roughly the same, in absolute terms, as the increase in real wages following a positive shock (in which case the adjustment is through both prices and nominal wages). Hence, the asymmetry in unemployment is smaller.

Other variables also display asymmetry in their response to negative and positive shocks. The asymmetry in the behavior of vacancies coupled with the asymmetry in the behavior of unemployment explains the asymmetry in the behavior of labor market tightness. Finally, there seems to be little asymmetry in the behavior of output and consumption. This is perhaps due to the symmetry in the productivity shock and the relatively small degree of asymmetry in unemployment.

It is also interesting to compare the behavior of the economy following shocks under the presence of DNWR to its behavior under symmetric adjustment cost function. Figure 7 displays the response of the economy to positive and negative shocks in the absence of DNWR. As expected, all variables display symmetry in their response to positive and negative shocks.

Figure 8 shows the response of the economy to a negative shock in the three possible cases: fully flexible nominal wages, symmetric nominal wage adjustment cost and DNWR. When nominal wages are fully flexible, not only that inflation is set at zero on average (recall Table 1), but inflation is also irresponsive on impact. Given that prices are costly to adjust and nominal wages are fully flexible, nominal wages fall instantaneously to allow for the drop in real wages. The role of DNWR is clearly revealed in this case: the response of inflation to a negative shock under downwardly nominal wages is significantly larger than its response to a negative shock when the adjustment cost is symmetric.

The fall in real wages under fully flexible nominal wages is considerably larger than under wage rigidity (of either type). Unemployment increase only slightly under fully flexible wages and it displays less persistence. In addition, the fall on vacancies and labor market tightness is considerably smaller under fully flexible nominal wages than under rigid wages. The larger falls in unemployment and hours under rigid wages than under fully flexible nominal wages lead to larger drops in output and consumption. In overall, and as expected, the case of symmetrically rigid wages is an intermediate case between the cases of fully flexible nominal wages and downwardly rigid nominal wages.

The discussion on optimal monetary policy can be summarized as follows. Under fully flexible nominal wages, inflation does not respond to negative shocks and it is always set at zero. When nominal wages are rigid and the adjustment cost function is symmetric, inflation responds to shocks but it is kept at zero on average. Finally, when nominal wages are downwardly rigid, the response of inflation is stronger on impact and monetary policy deviates, on average, from complete price stability.

7 Price Stabilization vs. Unemployment Stabilization

This section considers the performance of two extreme polices relative to optimal policy. In the first case, the monetary authority commits to full stabilization of prices at all dates and states (to which I refer as strict inflation targeting or zero-inflation policy). In the second, the monetary authority commits to stabilize unemployment at its steady state level.

When the monetary authority strictly targets zero inflation, unemployment responds more strongly than under the optimal policy (Figure 9). The initial response of unemployment for a shock of one standard deviation size is significantly larger than under optimal policy. The peak on the response, after about 3 quarters, is approximately three times as large under strict inflation targeting as under optimal policy. In addition, unemployment displays considerably more persistence under strict inflation targeting. In either case, unemployment displays the typical humped-shaped pattern that has been observed in previous studies with labor market frictions (e.g. Blanchard and Gali, 2008; Krause and Lubik, 2007).

Wage inflation falls more under strict inflation targeting than under constant unemployment and optimal policy (although in either case, the fall in wage inflation is relatively small due to the presence of DNWR). Since prices are fully stabilized, nominal wages must fall by more than under the optimal policy in order to allow for real wage adjustments. Note that the behavior of nominal wages under the constant unemployment regime is almost the same as under the optimal policy.

When the monetary authority fully stabilizes unemployment, inflation displays a stronger response than under the optimal policy. Intuitively, if unemployment cannot increase, prices must increase by more in order to generate the larger required decline in real wages. However, it is interesting to notice that after about 4 quarters, the behavior of inflation under the constant unemployment regime is similar to its behavior under optimal policy.

The most muted decline in real wages is under strict inflation targeting (which is a result of both DNWR and zero inflation), while the strongest decline is under the constant unemployment regime (because nominal wages remain almost unchanged, while inflation displays a larger increase than under optimal policy). This result is as expected since, when the monetary authority commits to fully stable employment, real wages must fall significantly so that the economy can adjust to the negative productivity shock.

Following the behavior of unemployment, the largest drop in output occurs under strict inflation targeting. Output reaches its trough after about 3 quarters, when unemployment peaks (and also when hours per worker reach their lowest point). The behavior of consumption is similar to the behavior of output, while the largest decline in labor market tightness occurs under strict inflation targeting, as vacancies fall strongly and unemployment increases considerably.

These responses suggest that strict inflation targeting is far from being optimal under DNWR. Full stabilization of prices in the presence of DNWR limits the ability of the economy to adjust to adverse shocks. Stabilizing unemployment, however, delivers responses similar to those under optimal policy. Welfare analyses show that welfare under a zero-inflation policy is lower by roughly 8.48 percent than welfare under the optimal policy. Welfare under full stabilization of unemployment is lower by only 0.30 percent than welfare under optimal policy.

The results of this section are in line with recent studies that suggest the need for deviations from full price stability. Blanchard and Gali (2008) show that strict inflation targeting delivers a welfare loss which is more than twice as large as under full stabilization of unemployment , and more than four times as large as under the optimal policy. My results here suggest higher welfare loss under strict inflation targeting than in Blanchard and Gali (2008), which can possibly be attributed to DNWR that makes zero-inflation policy even more undesirable. Faia (2008) suggests that, in the presence of real wage rigidities, the optimal Taylor-type rule should respond to unemployment alongside with inflation. Thomas (2008) also argues for incomplete stabilization of prices following shocks when nominal wages are rigid. Although these studies and the current one may differ in their focus (i.e. the type of wage rigidity), they all suggest that optimal policy should deviate from price stability following shocks. This study shows that, due to precautionary behavior, DNWR also leads to a significant deviation from full price stability on average.

8 Conclusions

This paper studies the optimal long-run inflation rate within a labor search and matching framework in the presence of downward nominal wage rigidity. When nominal wages are downwardly rigid, the optimal long-run inflation rate is around 2.0 percent. Optimal monetary policy deviates from full price stability to allow for real wage adjustments, particularly following adverse shocks, which promotes job creation and prevents an excessive increase in unemployment.

The results of this paper are related to Ramsey theory of smoothing wedges over time. In this study, the concern is over the "intertemporal wedge", which is defined here, generally speaking, as the deviation of the intertemporal marginal rate of substitution from the intertemporal marginal rate of transformation. Importantly, the asymmetric adjustment cost of nominal wages is part of this wedge. By setting a positive inflation rate, the Ramsey planner acts towards smoothing the intertemporal wedge and hence taking the economy closer to the efficient allocation. Indeed, the results suggest that the size and volatility of the wedge are both falling in the inflation rate as the degree of price rigidity is varied. The intertemporal wedge is virtually constant over time when prices are fully flexible.

Committing to a zero inflation rate over the business cycle has been found to perform the worst among other alternatives. Under a zero-inflation policy, the volatility of the intertemporal wedge is significantly higher (about 4 times as large as under optimal policy with sticky prices). The findings regarding labor market aggregates are similar; if the monetary authority strictly targets a zero inflation rate, the increases in unemployment is significantly larger than under the optimal policy. In addition, unemployment displays significantly higher volatility and reaches a higher level on average under full price stability, while vacancies are lower on average and far more volatile than under optimal policy.

The current paper can be further extended. One natural extension is to evaluate the performance of different Taylor-type rules compared to the optimal policy. Another extension is to allow for endogenous participation in the labor force. Finally, future work may consider the optimal long-run inflation rate in an economy with labor market frictions, price rigidity, DNWR and monetary distortions. It will be interesting to study the optimal inflation rate in this environment giving that each distortion calls for a different inflation rate.

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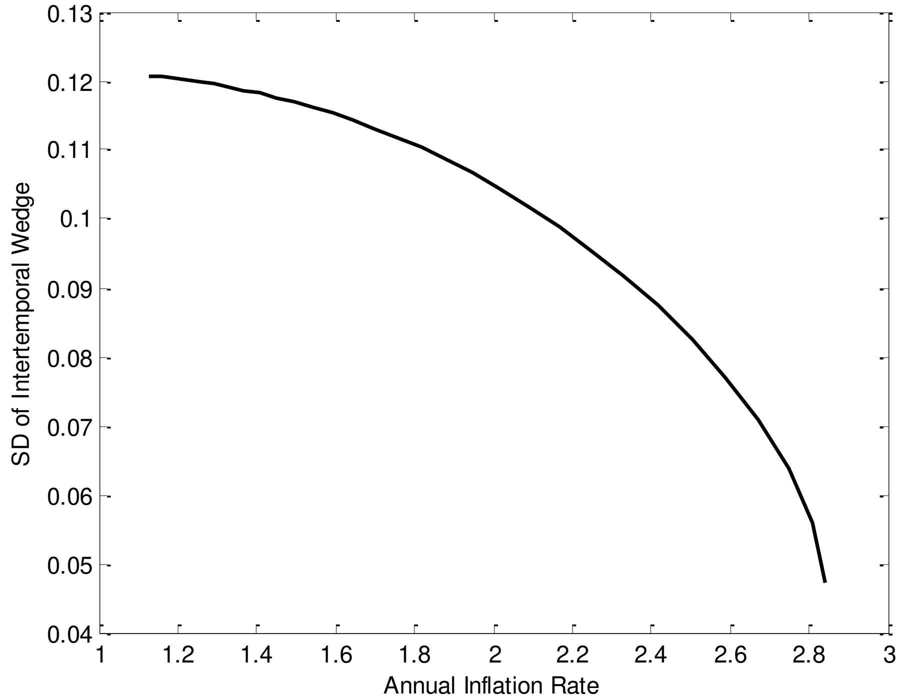

Figure 1- The standard deviation of the intertemporal wedge and the optimal annual inflation rate with varying the degree of price rigidity.

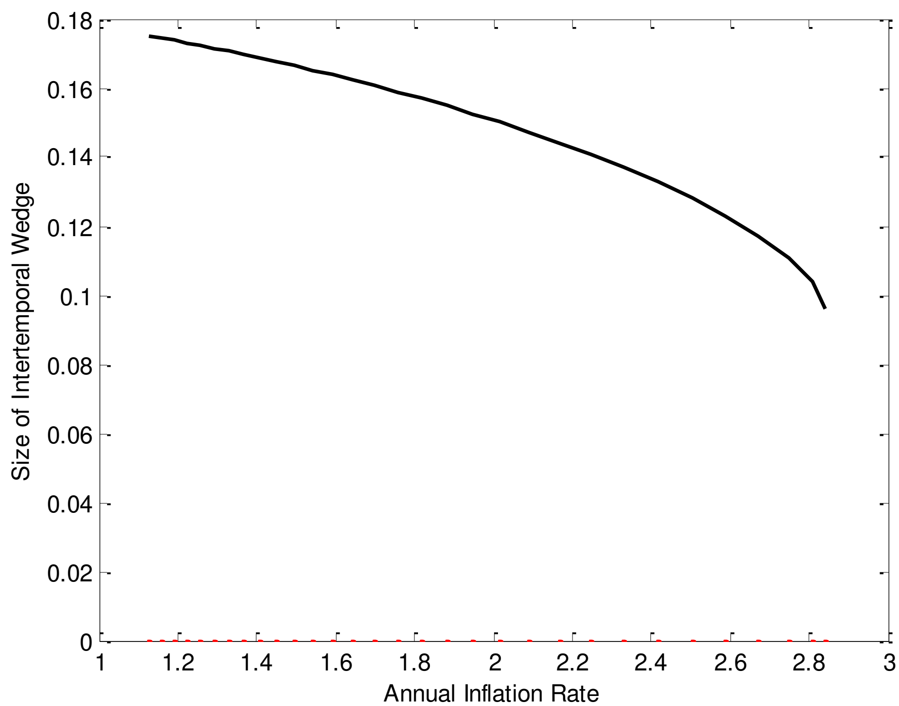

Figure 2- The size of the intertemporal wedge and the optimal annual inflation rate with varying the degree of price rigidity.

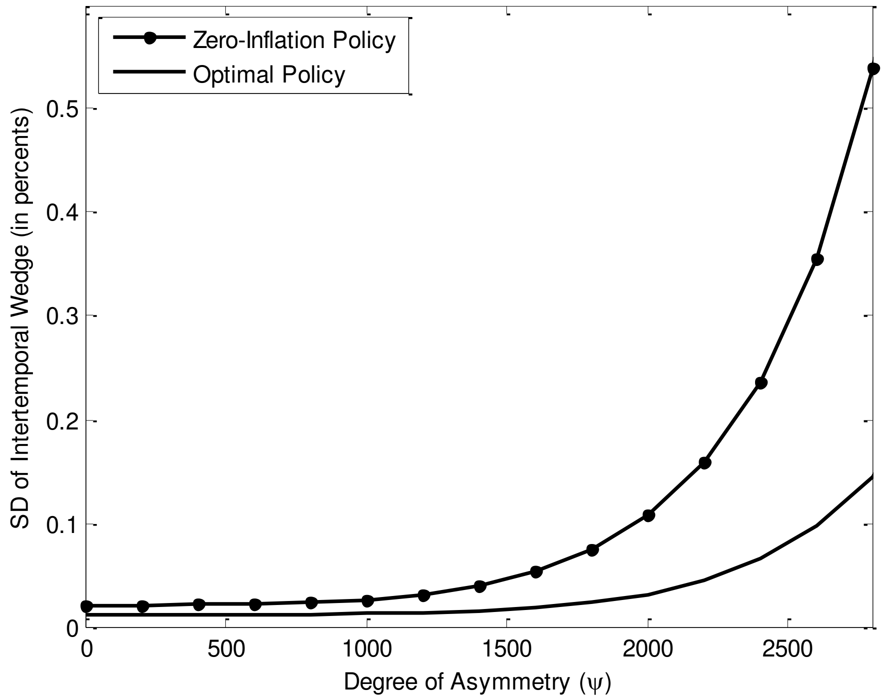

Figure 3- The standard deviation of the intertemporal wedge as a function of the degree of DNWR with *sticky* prices under optimal policy and zero-inflation policy.

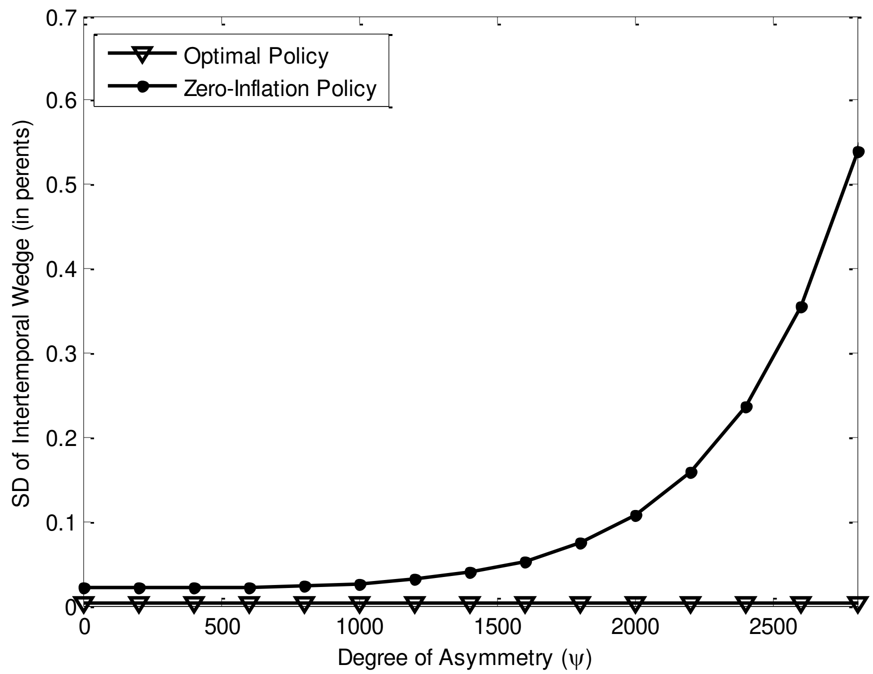

Figure 4- The standard deviation of the intertemporal wedge as a function of the degree of DNWR with *flexible* prices under optimal policy and zero-inflation policy.

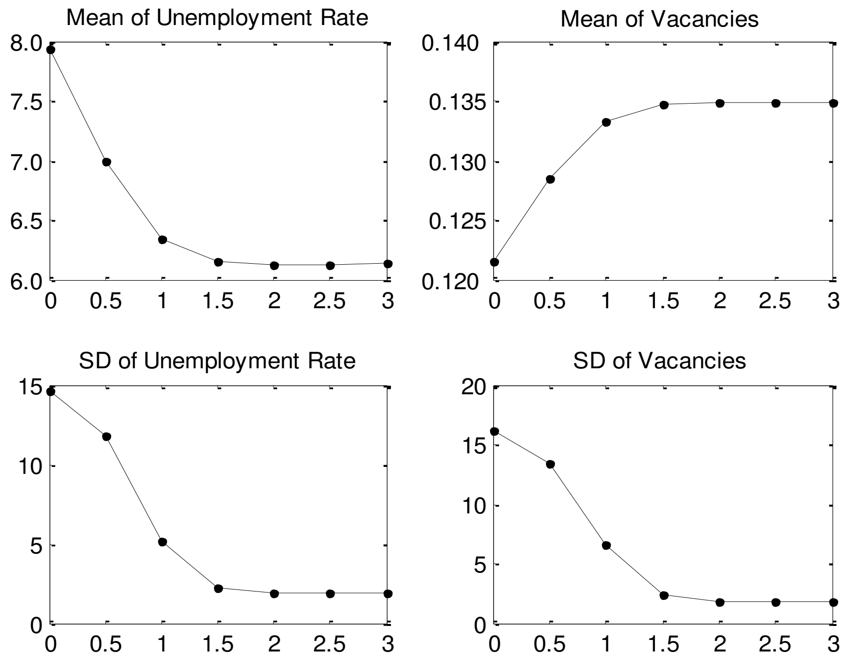

Figure 5: The mean value the unemployment rate (in percents), the mean of vacancies, the standard deviations of the unemployment rate and vacancies for various levels of annual inflation rates (in percents).

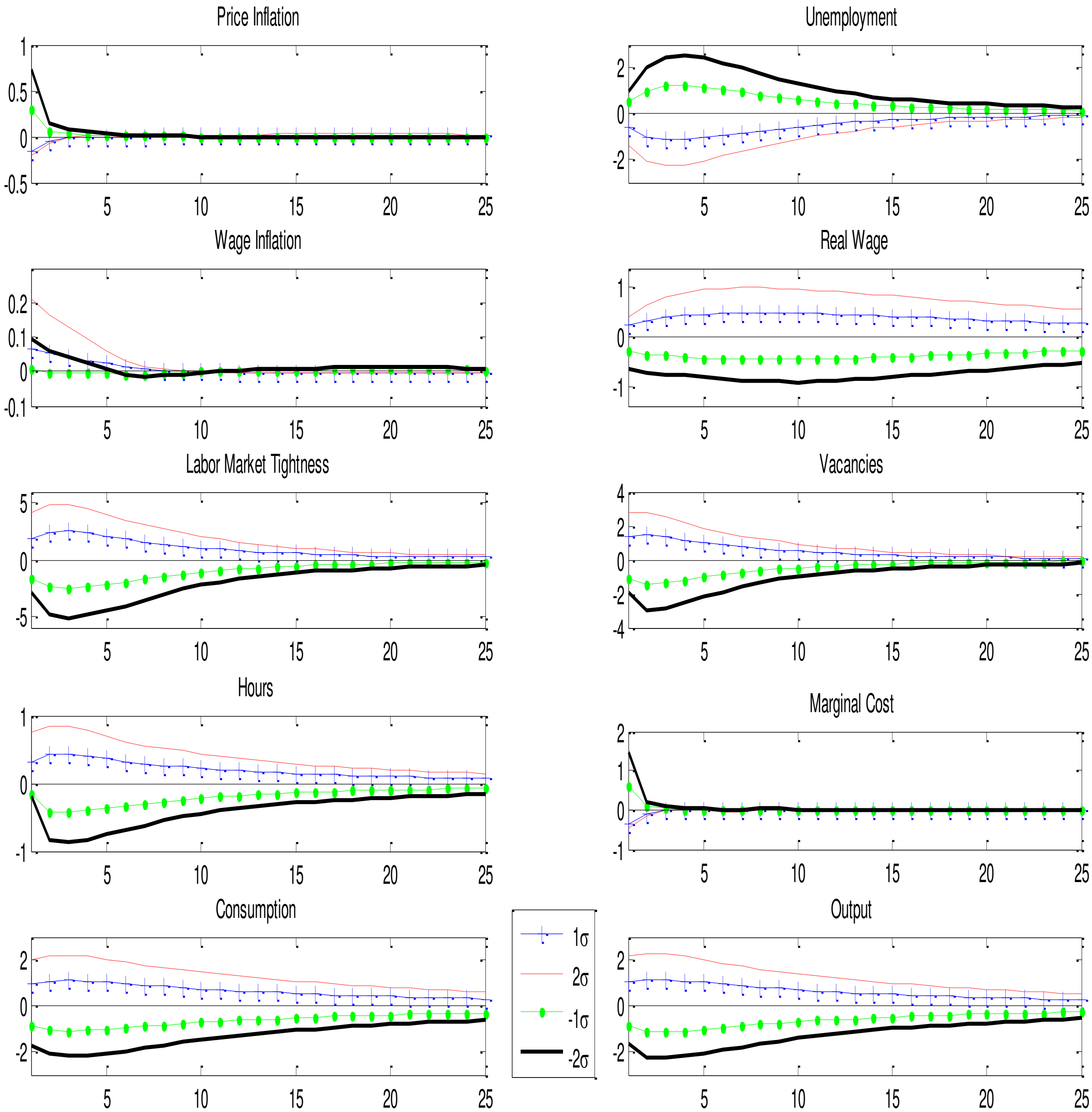

Figure 6: Response to a negative productivity shock with *asymmetric* wage adjustment cost function (percentage deviations from SS levels). 1σ : a positive 1 standard deviation shock. -1σ : a negative 1 standard deviation shock. 2σ : a positive 1 standard deviation shock. -2σ : a negative 1 standard deviation shock.

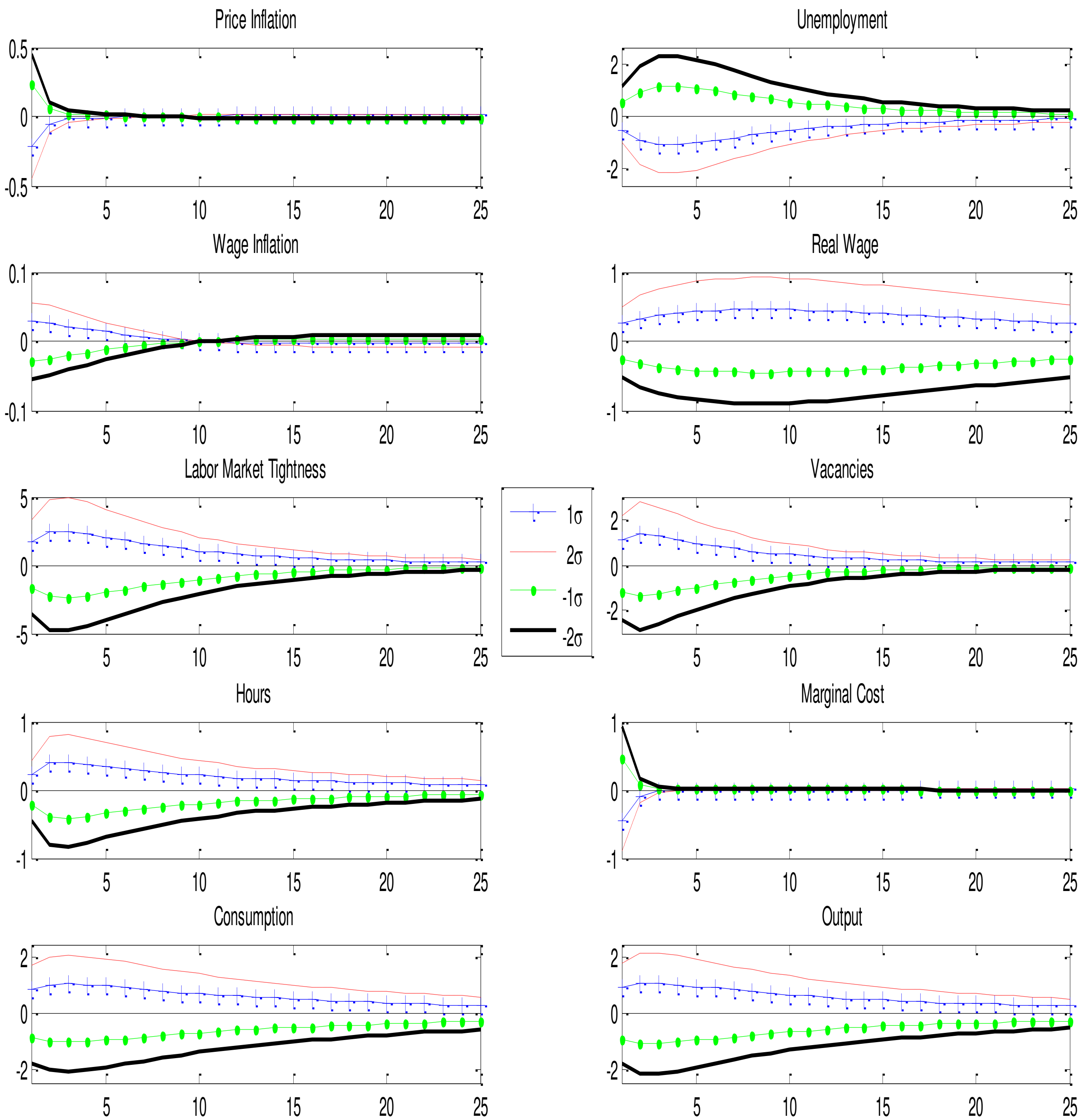

Figure 7: Responses to productivity shocks with *symmetric* wage adjustment cost function (percentage deviations from SS levels). 1σ : a positive 1 standard deviation shock. -1σ : a negative 1 standard deviation shock. 2σ : a positive 2 standard deviation shock. -2σ : a negative 2 standard deviation shock.

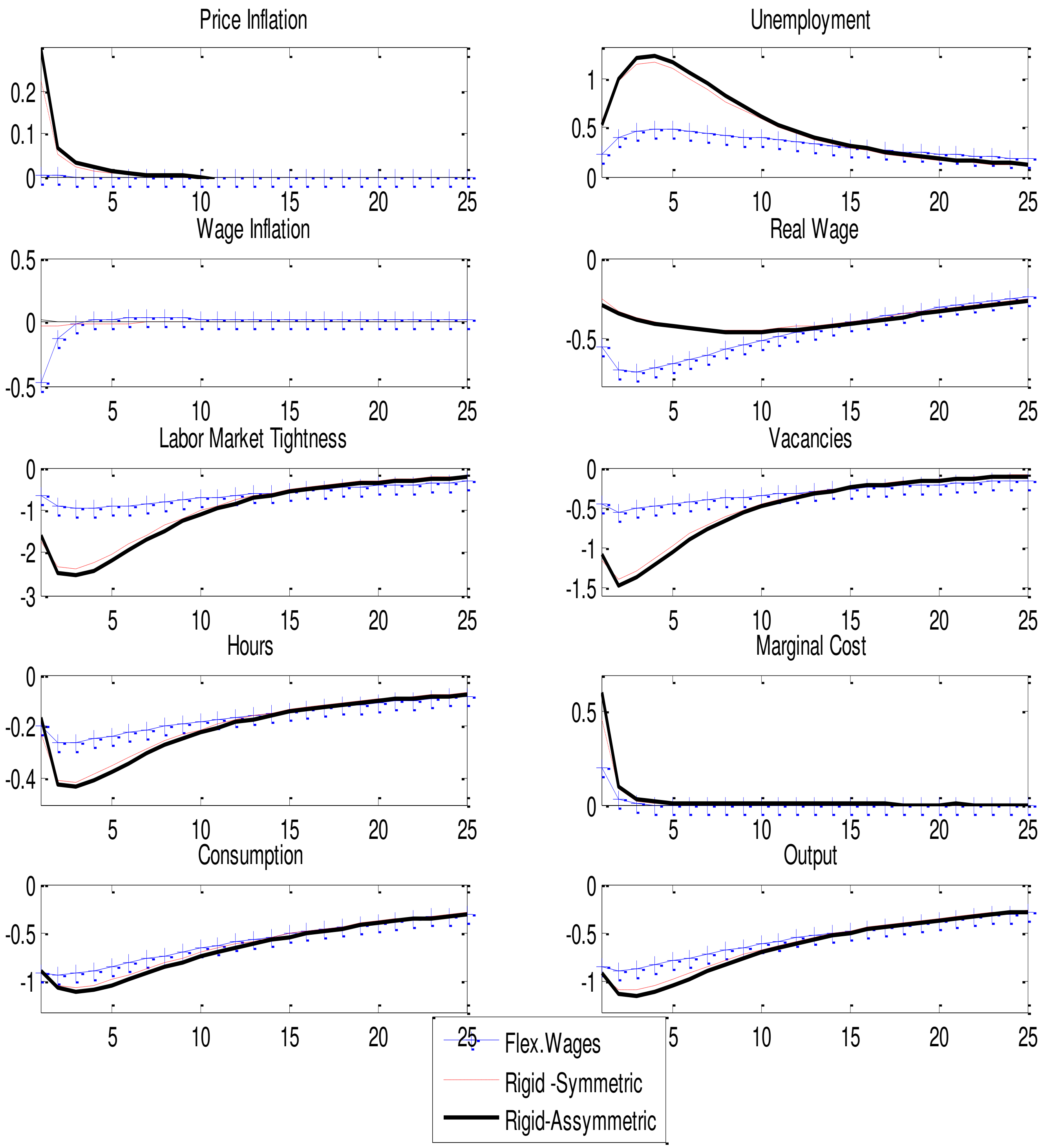

Figure 8: Responses to negative productivity shocks- Flexible nominal wages, symmetric wage adjustment cost function and asymmetric wage adjustment cost function (percentage deviations from SS levels).

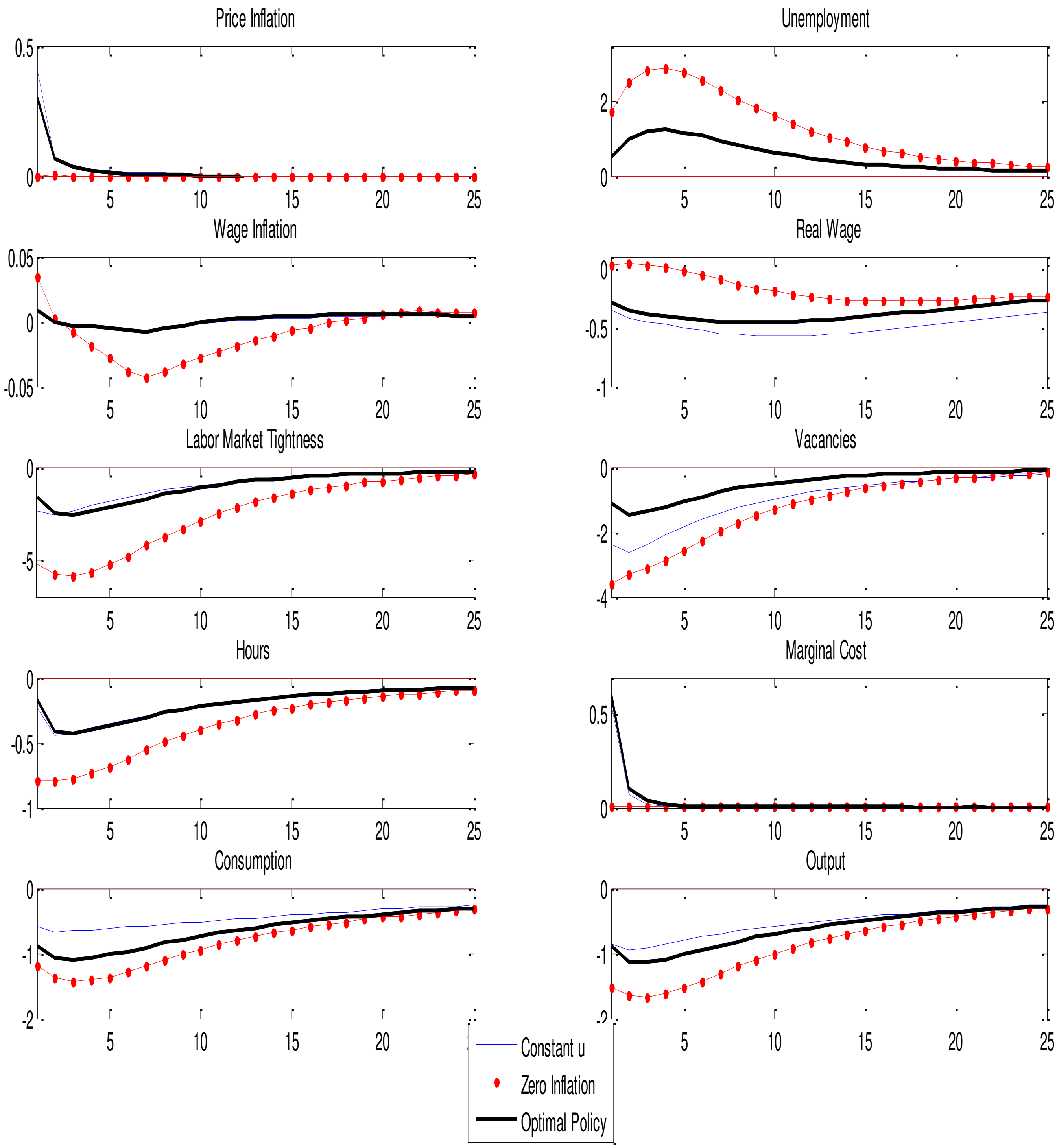

Figure 9: Responses to a 1 standard deviation negative productivity shocks with asymmetric wage adjustment cost function under different policy rules (percentage deviations from SS levels).

Appendix 1

A Efficient Allocations:

The problem of the social planner is to

$$maxE_0 \sum_{t=0}^{\infty} \beta^t \left[u(c_t) - n_t v(h_t) \right], \tag{A1}$$

subject to the sequence of the economy-wide resource constraints

$$n_t z_t f(h_t) - c_t - \gamma v_t = 0, \tag{A2}$$

and the sequence laws of motion of employment

$$(1-\rho)\left[n_t + m(1-n_t, v_t) \right] - n_{t+1} = 0 \tag{A3}$$

Let, λ_{1t} and λ_{1t} denote the Lagrange multipliers on constraints (A2) and (A3), respectively. Then, the first-order condition with respect to c_t, v_t and n_{t+1}, respectively, are

$$u_{ct} = \lambda_{1t}, \tag{A4}$$

$$-\gamma\lambda_{1t} + \lambda_{2t}\left[(1-\rho) m_v (1-n_t, v_t) \right] = 0, \tag{A5}$$

and,

$$-\lambda_{2t} - \beta v(h_{t+1}) + \beta E_t \lambda_{1t+1}\left[z_{t+1} f(h_{t+1}) \right] + \beta(1-\rho) E_t \lambda_{2t+1}\left[1 - m_u (1-n_t, v_t) \right] = 0. \tag{A6}$$

From (A5) we have

$$\lambda_{2t} = \frac{\gamma}{(1-\rho) m_v (1-n_t, v_t)} \lambda_{1t}, \tag{A7}$$

which, after substituting (A4), yields

$$\lambda_{2t} = \frac{\gamma}{(1-\rho) m_v (1-n_t, v_t)} u_{ct}. \tag{A8}$$

By substituting (A8) in (A6) and rearranging, we get

$$\frac{\gamma}{m_v (1-n_t, v_t)} = \beta(1-\rho) E_t \left[\left(\frac{u_{ct+1}}{u_{ct}} \right) \left(z_{t+1} f(h_{t+1}) - \frac{v(h_{t+1})}{u_{ct+1}} + \frac{\gamma\left[1 - m_u (1-n_{t+1}, v_{t+1}) \right]}{m_v (1-n_{t+1}, v_{t+1})} \right) \right], \tag{A9}$$

Finally, condition (A9) can also be written as

$$\frac{u_{ct}}{\beta u_{ct+1}}=\frac{(1-\rho)\left[z_{t+1}f(h_{t+1})-\frac{v(h_{t+1})}{u_{ct+1}}+\frac{\gamma\left[1-m_u(1-n_{t+1},v_{t+1})\right]}{m_v(1-n_{t+1},v_{t+1})}\right]}{\frac{\gamma}{m_v(1-n_t,v_t)}}. \tag{A10}$$

The left hand side is the Intertemporal Marginal Rate of Substitution (IMRS), while the right hand side is Intertemporal Marginal Rate of Transformation (IMRT). Efficiency, thus, requires the IMRT being equal to the IMRS for all t.

Finally, this condition can also be written as,

$$1=(1-\rho)E_t\left\{\left(\frac{\beta u_{ct+1}}{u_{ct}}\right)\left[\frac{z_{t+1}f(h_{t+1})-\frac{v(h_{t+1})}{u_{ct+1}}+\frac{\gamma\left[1-m_u(1-n_{t+1},v_{t+1})\right]}{m_v(1-n_{t+1},v_{t+1})}}{\frac{\gamma}{m_v(1-n_t,v_t)}}\right]\right\}. \tag{A11}$$

B The Intertemporal Wedge

In order to derive the intertemporal wedge, I make use of the vacancy-posting condition

$$\frac{\gamma}{q(\theta_t)}=\beta(1-\rho)E_t\left\{\left(\frac{u_{ct+1}}{u_{ct}}\right)\left[\varphi_{t+1}z_{t+1}f(h_{t+1})-w_{t+1}h_{t+1}-\Phi_{t+1}^{W}+\frac{\gamma}{q(\theta_{t+1})}\right]\right\}, \tag{B1}$$

and the wage bargaining condition

$$\frac{\omega_t}{1-\omega_t}\left[\varphi_t z_t f(h_t)-w_t h_t-\Phi_t^{W}+\frac{\gamma}{q(\theta_t)}\right]=w_t h_t-\frac{v(h_t)}{u_{ct}}-b+E_t\left[\frac{\omega_{t+1}}{1-\omega_{t+1}}\left(\frac{\gamma}{q(\theta_t)}-\gamma\theta_t\right)\right], \tag{B2}$$

where $\Phi_t^{W}=\frac{\phi}{\psi^2}\left(\exp[-\psi(\pi_t^{w}-1)]+\psi(\pi_t^{w}-1)-1\right)$.Using the properties of the matching function, we have $q(\theta_t)=\frac{m_v(1-n_t,v_t)}{(1-\zeta)}$. Then, conditions (B1) and (B2) can, respectively, be written as

$$\frac{\gamma(1-\zeta)}{m_v(1-n_t,v_t)}=\beta(1-\rho)E_t\left\{\left(\frac{u_{ct+1}}{u_{ct}}\right)\left[\varphi_{t+1}z_{t+1}f(h_{t+1})-w_{t+1}h_{t+1}-\Phi_{t+1}^{W}+\frac{\gamma(1-\zeta)}{m_v(1-n_{t+1},v_{t+1})}\right]\right\}, \tag{B3}$$

and,

$$\frac{\omega_t}{1-\omega_t}\left[\varphi_t z_t f(h_t)-w_t h_t-\Phi_t^{W}+\frac{\gamma(1-\zeta)}{m_v(1-n_t,v_t))}\right]=w_t h_t-\frac{v(h_t)}{u_{ct}}-b+E_t\left[\frac{\omega_{t+1}}{1-\omega_{t+1}}\left(\frac{\gamma(1-\zeta)}{m_v(1-n_t,v_t)}\left(1-\frac{m_u(1-n_t,v_t)}{\zeta}\right)\right)\right]. \tag{B4}$$

Rearranging condition (B4) yields:

$$w_t h_t=\omega_t\left[\varphi_t z_t f(h_t)-\Phi_t^{W}+\frac{\gamma(1-\zeta)}{m_v(1-n_t,v_t))}\right]+(1-\omega_t)\left(\frac{v(h_t)}{u_{ct}}+b-E_t\left[\left(\frac{\omega_{t+1}}{1-\omega_{t+1}}\right)\left(\frac{\gamma(1-\zeta)}{m_v(1-n_t,v_t)}\right)\left(1-\frac{m_u(1-n_t,v_t)}{\zeta}\right)\right]\right). \tag{B5}$$

After iterating one period ahead and collecting terms, equation (B5) can now be substituted into (B3) to yield:

$$\frac{\gamma(1-\zeta)}{m_v(1-n_t,v_t)}=\beta(1-\rho)E_t\left[\left(\frac{u_{ct+1}}{u_{ct}}\right)\left\{(1-\omega_{t+1})\left(\varphi_{t+1}z_{t+1}f(h_{t+1})-\frac{v(h_{t+1})}{u_{ct+1}}-\Phi^W_{t+1}-b+\frac{\gamma(1-\zeta)}{m_v(1-n_{t+1},v_{t+1})}\left(1+E_{t+1}\left[\frac{\omega_{t+2}}{1-\omega_{t+2}}\left(1-\frac{m_u(1-n_{t+1},v_{t+1})}{\zeta}\right)\right]\right)\right)\right\}\right]. \quad \text{(B6)}$$

Then, dividing by $(1-\zeta)$ gives

$$\frac{\gamma}{m_v(1-n_t,v_t)}=\beta(1-\rho)E_t\left[\left(\frac{u_{ct+1}}{u_{ct}}\right)\left\{\frac{(1-\omega_{t+1})}{(1-\zeta)}\left(\varphi_{t+1}z_{t+1}f(h_{t+1})-\frac{v(h_{t+1})}{u_{ct+1}}-\Phi^W_{t+1}-b+\frac{\gamma(1-\zeta)}{m_v(1-n_{t+1},v_{t+1})}\left(1+E_{t+1}\left[\frac{\omega_{t+2}}{1-\omega_{t+2}}\left(1-\frac{m_u(1-n_{t+1},v_{t+1})}{\zeta}\right)\right]\right)\right)\right\}\right]. \quad \text{(B7)}$$

By comparing (B7) with (A9), efficiency is restored if nominal wages are fully flexible or fully stabilized (i.e. $\Phi^W_{t+1}=0$, and hence $\omega_{t+1}=\eta$), the Hosios condition holds ($\zeta=\eta$), the unemployment benefits are zero (b=0), and no monopolistic power in the final-good sector (which implies $\varphi_{t+1}=1$). Finally, the wedge is implicitly defined by the comparing equation (B7) and (A9).

An analogous to condition (A10) can be obtained by rearranging terms in B(7), as follows

$$\frac{u_{ct}}{\beta u_{ct+1}}=\frac{(1-\rho)\left[\left\{\frac{(1-\omega_{t+1})}{(1-\zeta)}\left(\varphi_{t+1}z_{t+1}f(h_{t+1})-\frac{v(h_{t+1})}{u_{ct+1}}-\Phi^W_{t+1}-b+\frac{\gamma(1-\zeta)}{m_v(1-n_{t+1},v_{t+1})}\left(1+E_{t+1}\left[\frac{\omega_{t+2}}{1-\omega_{t+2}}\left(1-\frac{m_u(1-n_{t+1},v_{t+1})}{\zeta}\right)\right]\right)\right)\right\}\right]}{\frac{\gamma}{m_v(1-n_t,v_t)}}, \quad \text{(B8)}$$

where the left-hand side is the intertemporal rate of substitution (IMRS) and the right-hand side is the intertemporal rate of transformation (IMRT). Finally, rewrite condition (B8) as

$$1=(1-\rho)E_t\left\{\left(\frac{\beta u_{ct+1}}{u_{ct}}\right)\left[\frac{(1-\omega_{t+1})}{(1-\zeta)}\left(\frac{\varphi_{t+1}z_{t+1}f(h_{t+1})-\frac{v(h_{t+1})}{u_{ct+1}}-\Phi^W_{t+1}-b+\frac{\gamma(1-\zeta)}{m_v(1-n_{t+1},v_{t+1})}\left(1+E_{t+1}\left[\frac{\omega_{t+2}}{1-\omega_{t+2}}\left(1-\frac{m_u(1-n_{t+1},v_{t+1})}{\zeta}\right)\right]\right)}{\frac{\gamma}{m_v(1-n_t,v_t)}}\right)\right]\right\}. \quad \text{(B9)}$$

Comparison of the square brackets in (B9) with the square brackets of (A10) implicitly defines the intertemporal wedge.

C Optimal Monetary Policy Problem:

The optimal monetary policy problem is to choose $\{c_t, h_t, n_t, u_t, \theta_t, \varphi_t, w_t, \pi_t, \pi_t^w\}$ to maximize household's expected discounted lifetime utility subject to the resource constraint of the economy and the equilibrium conditions of firms and individuals. Formally,

$$Max E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{c_t^{1-\sigma}}{1-\sigma} - n_t \chi \frac{h_t^{1+\vartheta}}{1+\vartheta} \right], \tag{C1}$$

subject to,

$$\frac{\gamma}{q(\theta_t)} = \beta(1-\rho) E_t \left\{ \left(\frac{c_{t+1}^{-\sigma}}{c_t^{-\sigma}} \right) \left[\varphi_{t+1} z_{t+1} f(h_{t+1}) - w_{t+1} h_{t+1} - \frac{\phi}{\psi^2} \left(\exp[-\psi(\pi_{t+1}^w - 1)] + \psi(\pi_{t+1}^w - 1) - 1 \right) + \frac{\gamma}{q(\theta_{t+1})} \right] \right\}, \tag{C2}$$

$$\frac{\omega_t}{1-\omega_t} \left[\varphi_t z_t f(h_t) - w_t h_t - \frac{\phi}{\psi^2} \left(\exp[-\psi(\pi_t^w - 1)] + \psi(\pi_t^w - 1) - 1 \right) + \frac{\gamma}{q(\theta_t)} \right] = w_t h_t - \frac{v(h_t)}{u_{ct}} - b + E_t \left[\frac{\omega_{t+1}}{1-\omega_{t+1}} \left(\frac{\gamma}{q(\theta_t)} - \gamma \theta_t \right) \right], \tag{C3}$$

$$\frac{\Gamma_t}{1-\Gamma_t} \left[\varphi_t z_t f(h_t) - w_t h_t - \frac{\phi}{\psi^2} \left(\exp[-\psi(\pi_t^w - 1)] + \psi(\pi_t^w - 1) - 1 \right) + \frac{\gamma}{q(\theta_t)} \right] = w_t h_t - \frac{v(h_t)}{u_{ct}} - b + E_t \left[\frac{\Gamma_{t+1}}{1-\Gamma_{t+1}} \left(\frac{\gamma}{q(\theta_t)} - \gamma \theta_t \right) \right], \tag{C4}$$

$$1 - \phi^p (\pi_t - 1)\pi_t + \beta \phi^p E_t \left[\left(\frac{u_{ct+1}}{u_{ct}} \right) (\pi_{t+1} - 1)\pi_{t+1} \frac{y_{t+1}}{y_t} \right] = \varepsilon(1 - mc_t), \tag{C5}$$

$$\frac{w_t}{w_{t-1}} - \frac{\pi_t^w}{\pi_t} = 0, \tag{C6}$$

$$1 - n_t - u_t = 0, \tag{C7}$$

$$n_{t+1} - (1-\rho)(n_t + \sigma_m u_t \theta_t^{1-\zeta}) = 0, \tag{C8}$$

and,

$$n_t z_t f(h_t) - c_t - \gamma \theta_t u_t - \frac{\phi}{\psi^2} \left(\exp[-\psi(\pi_t^w - 1)] + \psi(\pi_t^w - 1) - 1 \right) n_t - \frac{\psi^p}{2} (\pi_t - 1)^2 n_t z_t f(h_t) = 0. \tag{C9}$$

D Deriving the Philips Curve:

I show here the derivation of the Phillips curve (condition 20 in the text) which is the outcome of the first-order condition with respect to the price P_{jt}. The firm *j* chooses the price P_{jt} to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \left\{ \frac{P_{jt}}{P_t} y_{jt} - n_{jt} w_{jt} h_{jt} - \gamma v_{jt} - \frac{\phi}{\psi^2} \left(\exp[-\psi(\frac{W_{jt}}{W_{jt-1}} - 1)] + \psi(\frac{W_{jt}}{W_{jt-1}} - 1) - 1 \right) n_{jt} - \frac{\phi^p}{2} \left(\frac{P_{jt}}{P_{jt-1}} - 1 \right) y_t \right\}, \quad \text{(D1)}$$

subject to the sequence of laws of motion of employment, and the :

$$n_{jt+1} = (1-\rho)(n_{jt} + v_{jt} q(\theta_t)), \quad \text{(D2)}$$

and the downward-sloping demand function for its product

$$z_t n_{jt} f(h_{jt}) = \left[\frac{P_{jt}}{P_t} \right]^{-\varepsilon} y_t \ . \quad \text{(D3)}$$

Associating a Lagrange multiplier φ_{jt} with (D3), the first-order condition with respect to the price P_{jt} reads

$$\begin{aligned} &\beta^t \frac{\lambda_t}{\lambda_0} \left[(1-\varepsilon) \left(\frac{P_{jt}}{P_t} \right)^{-\varepsilon} \frac{y_t}{P_t} + \varepsilon \varphi_{jt} \left(\frac{P_{jt}}{P_t} \right)^{-\varepsilon-1} \frac{y_t}{P_t} - \phi^p \left(\frac{P_{jt}}{P_{jt-1}} - 1 \right) \frac{y_t}{P_{jt-1}} \right] + \\ &\beta^{t+1} E_t \left\{ \left(\frac{\lambda_{t+1}}{\lambda_0} \right) \left[-\phi^p \left(\frac{P_{jt+1}}{P_{jt}} - 1 \right) \left(\frac{-P_{jt+1}}{P_{jt}^2} \right) y_{t+1} \right] \right\} = 0 \end{aligned} \quad . \quad \text{(D4)}$$

In equilibrium, all firms set the same price (i.e. $P_{jt} = P_t$ for all *j*). Imposing symmetry on condition (D4) and canceling terms give

$$\lambda_t \left[(1-\varepsilon) \frac{y_t}{P_t} + \varepsilon \varphi_t \frac{y_t}{P_t} - \phi^p \left(\frac{P_t}{P_{t-1}} - 1 \right) \frac{y_t}{P_{t-1}} \right] + \beta E_t \left\{ \lambda_{t+1} \left[-\phi^p \left(\frac{P_{t+1}}{P_t} - 1 \right) \left(\frac{-P_{t+1}}{P_t^2} \right) y_{t+1} \right] \right\} = 0 \quad \text{(D5)}$$

Multiplying by $\dfrac{P_t}{y_t}$ yields

$$\lambda_t \left[(1-\varepsilon) + \varepsilon_t \varphi_t - \phi^p \left(\frac{P_t}{P_{t-1}} - 1 \right) \frac{P_t}{P_{t-1}} \right] + \beta E_t \left\{ \lambda_{t+1} \left[\phi^p \left(\frac{P_{t+1}}{P_t} - 1 \right) \left(\frac{P_{t+1}}{P_{t+1}} \right) \frac{y_{t+1}}{y_t} \right] \right\} = 0 \quad \text{(D6)}$$

Defining $\pi_t = \dfrac{P_t}{P_{t-1}}$, rearranging and using the fact that $\dfrac{\lambda_{t+1}}{\lambda_t} = \dfrac{u_{ct+1}}{u_{ct}}$, we get

$$1 - \phi^p (\pi_t - 1)\pi_t + \beta \phi^p E_t \left[\left(\frac{u_{ct+1}}{u_{ct}} \right) (\pi_{t+1} - 1)\pi_{t+1} \frac{y_{t+1}}{y_t} \right] = \varepsilon (1 - \varphi_t), \quad \text{(D7)}$$

which is equation (20) in the text.