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The inflation-output tradeoff: which type of labor market rigidity is to be blamed?

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The Inflation-Output Tradeoff: Which Type of Labor Market Rigidity Is to Be Blamed?

by Christian Merkl

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The Inflation-Output Tradeoff: Which Type of Labor Market Rigidity Is to Be Blamed?*

Christian Merkl

Abstract:

In the standard New Keynesian sticky price model the central bank faces no contradiction between the stabilization of inflation and the stabilization of the welfare relevant output gap after a productivity shock hits the economy. When the standard model is enhanced by real wage rigidities or labor turnover costs, an endogenous short-run inflation-output tradeoff arises. This paper compares the implications of the two labor market rigidities. It argues that economists and policymakers alike should pay more attention to labor turnover costs for the following reasons. First, a model with labor turnover costs generates impulse response functions that are more in line with the empirical evidence than those of a model with real wage rigidities. Second, labor turnover costs are the dominant source for the inflation-output tradeoff when both rigidities are present in the model. And finally, there is stronger empirical evidence for the existence of labor turnover costs than for real wage rigidities.

Keywords: monetary policy, real wage rigidity, labor turnover costs, unemployment, tradeoff

JEL classification: E24, E32, E52, J23

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1 Introduction

In the standard sticky price model, the stabilization of prices (i.e., a zero inflation policy) in response to supply side shocks (e.g., productivity shocks or oil price shocks) is equivalent to the stabilization of the welfare relevant output gap (i.e. the central bank does not face any meaningful inflation-output tradeoff).¹ Blanchard and Galí (2007) consider this theoretical outcome² to be one of the key weaknesses of the New Keynesian model because it is at odds with the empirical literature as well as with central bankers' perceptions.

In this paper I enhance the standard New Keynesian model with two simple labor market rigidities that generate an endogenous inflation-output tradeoff. First, I integrate real wage rigidities (RWRs) à la Blanchard and Galí (2007, henceforth BG). Second, I integrate a labor market with heterogeneous worker productivity and labor turnover costs (i.e., hiring and firing costs, henceforth LTCs) à la Lechthaler, Merkl, and Snower (2008, henceforth LMS). Third, I combine the two labor market rigidities.

I argue that labor turnover costs are more likely to be blamed for the short-run inflation-output tradeoff that central banks may face than RWRs. First, in contrast to RWRs, LTCs do not run afoul of the Barro and Lucas critiques. Second, a model with LTCs generates more realistic impulse response functions than a model with RWRs. Third, LTCs are the dominant source for the tradeoff when the theoretical model contains both labor market rigidities. Fourth, while the evidence for LTCs is well established, the evidence for RWRs indicates that they are only relevant for current jobs but not for new jobs. This makes the short-run inflation-output tradeoff disappear.

The remainder of the paper is organized as follows. Section 2 briefly outlines the underlying models, placing particular emphasis on the labor market. Section 3 describes the parametrization of the model. Section 4 shows the impulse response functions in reaction to productivity shocks under different labor market rigidities and interest rate rules. Furthermore, it briefly discusses the short-run inflation-output tradeoff under the different regimes. Section 5 discusses the potential role of the two labor market rigidities in generating an inflation-output tradeoff. Section 6 concludes.

2 The Model

I take the standard New Keynesian model and modify the labor market structure in three ways (see Figure 1). First, I introduce a RWRs à la BG in a standard representative agent model. Second, I assume that households face idiosyncratic operating cost shocks and that there are linear hiring and firing costs (i.e., LTCs) à la LMS. In a third step, I combine RWRs and LTCs.

¹This is not true for cost-push shocks. However, such shocks are not microfounded, but introduced in ad hoc manner.

²They call it the "divine coincidence."

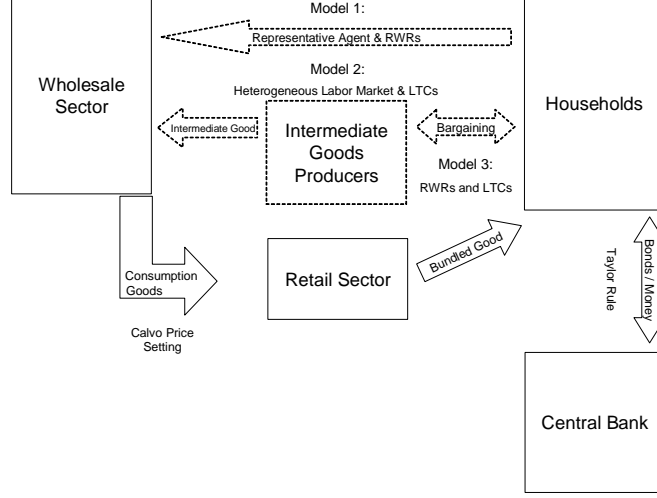


Figure 1: The Three Model Modifications (Changed Model Parts Indicated by Dashed Lines)

For brevity, I only show the labor market equations below because all other parts of the model are absolutely standard. The entire set of equations can be found in the Technical Appendix.

2.1 The Model with RWRs

I use a standard New Keynesian sticky price model, enhanced with a sluggish real wage adjustment, as proposed by BG:

$$W_t/P_t = (W_{t-1}/P_{t-1})^\gamma (C_t^\sigma N_t^\varphi)^{1-\gamma}, \quad (1)$$

where γ is the degree of real wage rigidity, σ is the elasticity of intertemporal substitution, and φ is the labor disutility parameter.³ $\gamma = 0$ nests the special case in which the wage adjusts flexibly.

The model details are outlaid in BG and can be found in the Appendix.⁴ BG show analytically that the central bank faces a short-run inflation-output tradeoff in the presence of RWRs.

³Under the assumption that households' utility is separable and has the following form:

$$U = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}.$$

⁴For the nonlinear version thereof, see Ascari and Merkl (2009).

2.2 The Model with LTCs

I enhance the standard New Keynesian model by a labor market with heterogeneous operating costs, LTCs, and unemployment. In doing so I focus on the decisions of the intermediate goods firm, which I add to the standard model (see Figure 1). Further model details can be found in LMS.⁵

Intermediate goods firms (which sell intermediate goods to final goods sector firms) hire labor to produce the intermediate good Z . Their production function is:

$$Z_t = A_t N_t, \quad (2)$$

where A is technology and N is the number of employed workers. The parameter A is subject to temporary aggregate technology shocks with an autoregressive component, ρ_a , and the standard deviation μ_a . Intermediate goods producers sell the product at relative price, $MC_t = P_{z,t}/P_t$ ⁶, which they take as given in a perfectly competitive environment, where P_z is the absolute price of the intermediate good and P is the economy's overall price level.

I assume that every worker (employed or unemployed) is subject to an idiosyncratic operating cost shock, ε_t , at the beginning of the period, which is known by the firm and which determines the employment decision. The operating costs can be interpreted as an idiosyncratic shock to workers' productivity or as a firm-specific idiosyncratic cost shock. The firms learn the value of the operating costs of every worker at the beginning of a period and base their employment decisions on this value, i.e. an unemployed worker associated with a favorable shock will be employed while an employed worker associated with a bad shock will be fired. Hiring and firing is not costless, firms have to pay linear hiring costs, H , and linear firing costs, F , both measured in terms of the final consumption good. Hiring and firing costs drive a wedge between the hiring decision and the firing decision. In their presence, the retention rate (i.e., 1 minus the firing rate) is always higher than the hiring rate (see Figure 2 in LMS).

Each worker generates the following profit:⁷

$$\begin{aligned} \tilde{\Pi}_{I,t}(\varepsilon_t) = & A_t MC_t - W_t/P_t - \varepsilon_t \\ & + E_t \sum_{i=t+1}^{\infty} \Delta_{t,i} \left[(1 - \phi_i)^{i-t} \begin{pmatrix} A_i MC_i - W_i/P_i - \\ E_t(\varepsilon_i | 1 - \phi_i) \\ - \phi_i F (1 - \phi_i)^{i-t-1} \end{pmatrix} \right], \quad (3) \end{aligned}$$

⁵For the model in partial equilibrium, see Snower and Merkl (2006).

⁶These are the marginal costs of the monopolistically competitive firms, which adjust their prices in staggered manner.

⁷Note that transitory productivity shocks as modeled in this paper do not affect the structure of the operating costs. LMS show that hiring and firing rates are independent of technological progress if the operating costs are multiplied by the respective growth rate. Without loss of generality, I assume in this paper that there is no trend productivity growth, but just transitory shocks.

where ϕ is the separation probability, $E_t(\varepsilon_{t+1}|1 - \phi_{t+1})$ the expected value of operating costs for an insider (i.e., conditional on retention), and $\Delta_{t,i}$ the stochastic discount factor from period t to j (i.e., the subjective discount factor β weighted with the respective periods' marginal consumption utility). Real wages, W_t/P_t , are determined by a Nash bargain between employees and the firm.⁸

Unemployed workers are hired whenever their operating cost does not exceed a certain threshold, such that the expected present value of this worker is higher than the hiring cost, i.e., $\tilde{\Pi}_{I,t}(\varepsilon_t) > H$. Thus, the hiring threshold, $v_{h,t}$, (the value of the operating cost at which the firm is indifferent between hiring and not hiring an unemployed worker) is defined by

$$\tilde{\Pi}_{I,t}(v_{h,t}) = A_t MC_t - W_t/P_t - v_{h,t} + E_t(\Delta_{t,t+1} \tilde{\Pi}_{I,t+1}) = H. \quad (4)$$

Unemployed workers whose operating cost is lower than this value are hired, while those whose operating cost is higher are not. The resulting hiring probability is given by

$$\eta_t = \Gamma(v_{h,t}), \quad (5)$$

where Γ is the cumulative density function of ε . The firm will fire a worker whenever $\tilde{\Pi}_t(\varepsilon_t) < -F$, i.e., when the operating costs are so high that it is more profitable for the firm to pay the cost of firing the worker. This defines the firing threshold (the value of the operating cost at which the firm is indifferent between firing and retaining the worker) as

$$\tilde{\Pi}_{I,t}(v_{f,t}) = A_t MC_t - W_t/P_t - v_{f,t} + E_t(\Delta_{t,t+1} \tilde{\Pi}_{I,t+1}) = -F, \quad (6)$$

and the separation rate is,

$$\phi_t = 1 - \Gamma(v_{f,t}). \quad (7)$$

I obtain the usual employment dynamics curve:

$$n_t = n_{t-1}(1 - \phi_t - \eta_t) + \eta_t, \quad (8)$$

where n is the employment rate.

2.3 An Analytical Comparison

It is well known that the loglinearized Phillips Curve in the standard New Keynesian model looks as follows⁹:

⁸This gives the wage equation $W_t/P_t = \zeta(A_t MC_t + S_t) + (1 - \zeta)B_t$, where ζ is the workers' bargaining power, B is the real value of the unemployment benefits, and S is the cost of the firm in case of disagreement. This bargaining mechanism is chosen for analytical simplicity. However, the main conclusions also remain robust for other bargaining schemes (details are available on request).

⁹Lower-case variables with a $\hat{\cdot}$ denote deviations from the steady state.

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \frac{(1 - \beta\theta)(1 - \theta)}{\theta} \widehat{mc}_t, \quad (9)$$

where θ is the Calvo probability of not readjusting prices in a given quarter and mc are the marginal costs. In the most simple model (with a constant returns to labor production function) the marginal costs are equal to the wage divided by productivity. It is easy to see that RWRs (see equation 1) drive an intertemporal wedge between the first best level of the wage (determined by the marginal rate of substitution between the utility of consumption and the disutility of labor) and the actual wage. This makes the marginal cost adjustment more sluggish than in the standard model and leads to intertemporal inflation-output tradeoffs (see BG for more analytical details).

In the model with LTCs, marginal costs are determined by the wage (as in the standard model), the hiring threshold, $v_{h,t}$, the hiring costs, H , and the expected discounted future profits, $E_t(\Delta_{t,t+1} \tilde{\Pi}_{I,t+1}(\varepsilon_{t+1}))$.

$$MC_t = \frac{W_t}{A_t} - \frac{v_{h,t}}{A_t} + \frac{H}{A_t} + \frac{E_t(\Delta_{t,t+1} \tilde{\Pi}_{I,t+1}(\varepsilon_{t+1}))}{A_t} \quad (10)$$

In this context wages loose part of their allocative role, as marginal costs depend on two additional components, namely the marginal workers' hiring threshold and the expected future profits of an average worker. These two components vary endogenously and drive a wedge between marginal costs in a frictionless economy and the marginal costs in an economy with LTCs. In the latter a productivity shock is associated with an endogenous microfounded cost-push shock, creating an inflation-output tradeoff. The higher the LTCs are, the more severe is this tradeoff.¹⁰

2.4 Monetary Policy

To close the model, the conduct of monetary policy has to be specified. For comparability reasons it is assumed that monetary policy follows a standard Taylor rule in both model economies :

$$\left(\frac{1 + i_t}{1 + \bar{i}} \right) = \left(\frac{\pi_t}{\bar{\pi}} \right)^{\alpha_\pi} \left(\frac{Y_t}{\bar{Y}} \right)^{\alpha_y}, \quad (11)$$

where π_t is the gross inflation rate, $\bar{\pi}$ is the central bank inflation target, Y_t is the actual output, \bar{Y} is the steady state output level and \bar{i} is the steady state interest rate (for a given output and inflation level). A hawkish central bank is modeled by increasing the weight on inflation, α_π .

¹⁰For a detailed illustration of this issue and the effects of LTCs on optimal monetary policy see Faia et al. (2009).

3 Calibration

The models are calibrated to represent economies with nonnegligible labor market rigidities. The real wage rigidities are set to $\gamma = 0.6$ (see, e.g., Blanchard and Galí, 2008).¹¹ In the LMS model the operating costs are chosen to replicate the quarterly steady state labor market flows of a typical continental European country ($\phi = 0.02$, $\eta = 0.2$).¹² The quarterly probability of not readjusting prices in the Calvo model, θ , is set to 0.75, the elasticity of substitution in the monopolistic sector, ε , is set to 10, bargaining power, ζ , is set to 0.5 and the unemployment benefits, b , are set to 70% of a workers' average wage. A summary of all calibration values can be found in Table 1.

Table 1: Parametrization

β	0.99	φ	1	μ_a	0.01	$\alpha_{\pi,1}$	1.5	γ_1	0
σ	1	F	0.6	ρ_a	0.95	$\alpha_{\pi,2}$	5	γ_2	0.6
ε	10	H	0.1	$E(\varepsilon)$	0	α_y	0.125	A	1
θ	0.75	b	0.5	sd	0.53	ζ	0.5	S	0.2879

4 Results

4.1 The Standard Model

For comparability reasons, I show the reaction of the standard sticky price New Keynesian model (without any real rigidities) to a negative productivity shock under two different Taylor rules (a conventional rule with weight $\alpha_{\pi,1} = 1.5$ on inflation and weight $\alpha_y = 0.125$ on output and a hawkish rule with $\alpha_{\pi,2} = 5$ and $\alpha_y = 0.125$). As can be seen in Figure 2, the central bank with a hawkish rule brings the inflation path closer to zero than the central bank with a standard rule. Independently of the rule, the model shows the well-known increase in employment in response to the negative productivity shock,¹³ albeit the employment movement is less pronounced under the hawkish rule. Hence, in the standard model a hawkish central bank reduces both the employment and the inflation fluctuations more than the conventional central bank. This increases households' utility, as the lower inflation volatility reduces the associated price distortions and the lower employment volatility reduces the intertemporal disutility of labor.

¹¹For comparability, I also show the impulse response functions of the standard model ($\gamma = 0$).

¹²A logistic distribution is chosen for the idiosyncratic operating cost shock. The mean, $E(\varepsilon)$, is normalized to zero. The dispersion of the distribution, sd , and the fall-back option of the firm under disagreement, $-S$, are chosen to obtain the desired flow rates.

¹³The smaller output must be produced by a higher labor input due to the lower productivity.

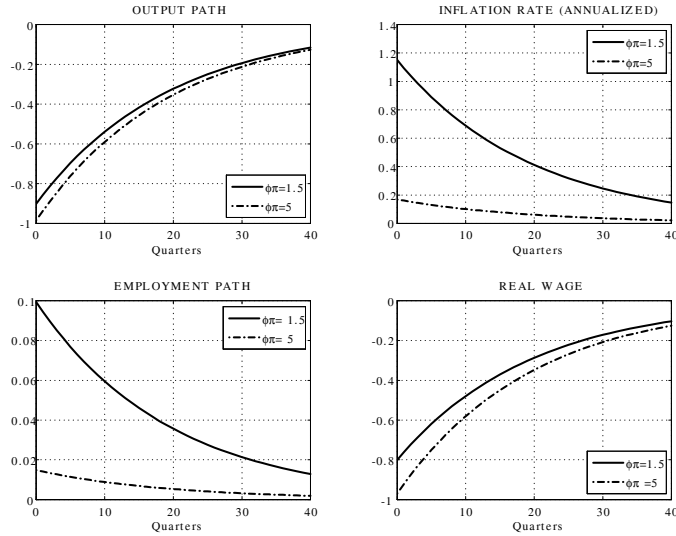


Figure 2: Standard Model (All Variables Expressed as Percent Deviations from the Steady State)

In principal, the monetary authority can choose an interest rate path that stabilizes both the inflation and the employment fluctuations at zero, which maximizes households' utility (thereby stabilizing the welfare relevant output gap to zero). Thus, there is no endogenous short-run inflation-output tradeoff in response to a productivity shock.

4.2 The Model with RWRs

The picture looks different when the standard model is enhanced with RWRs. The central bank with the hawkish rule is again more successful in stabilizing prices than the central bank with the standard rule. However, the former causes more substantial employment fluctuations (see Figure 3). The reason is straightforward. RWRs lead to a more sluggish downward adjustment of real wages than in the standard model. In response to the more substantial pressure of marginal costs, firms raise their prices and the hawkish central bank reacts by setting a higher nominal interest rate than in the standard model. Thus, households' consumption and firms' production are reduced more than in the standard model.

The sluggish real wage adjustment prevents an optimal adjustment of the labor supply (i.e., in a frictionless labor market, wages drop by more and lead to a different employment adjustment). As a consequence, smaller deviations from zero inflation can only be achieved when the central bank accepts larger em-

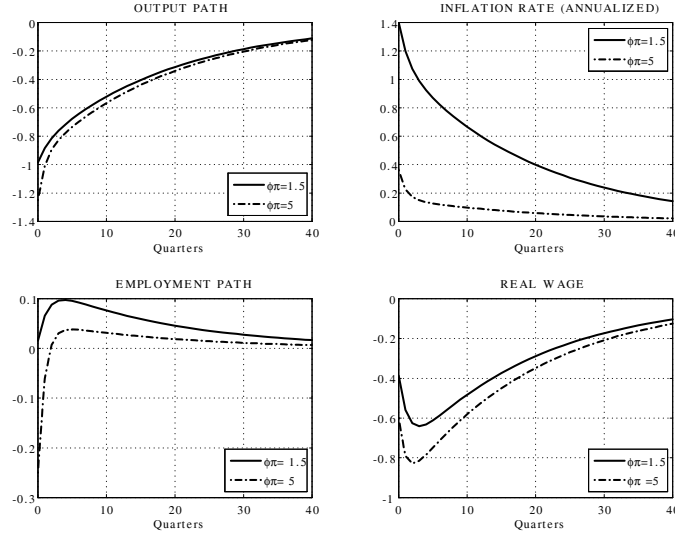


Figure 3: Model with Real Wage Rigidities

ployment fluctuations. The central bank faces an endogenous inflation-output tradeoff in response to productivity shocks.

4.3 The Model with LTCs

There is the same qualitative tradeoff in the model with LTCs, which drive a wedge between workers' retention rates (i.e., the probability that an employed worker stays within the firm) and workers' job finding rates (i.e., the probability that they will be hired). A negative productivity shock makes workers less profitable for firms because their future present value of profits goes down. Therefore, firms reduce the hiring rate and increase the firing rate. However, LTCs make the output adjustment more muted than in a frictionless labor market because of the aforementioned wedge (this is visible when comparing the output graphs in Figures 2 and 4).

As in the previous examples, in response to the negative productivity shock the central bank with the more hawkish rule sets a higher nominal interest rate than the central bank with the standard rule. This reduces households' consumption and firms' production more than with the standard rule. As a consequence, firms reduce their hiring rates more and increase their firing rates more than with the standard rule, which leads to larger downward employment fluctuations.

Thus, as with the RWRs, an endogenous inflation-output tradeoff occurs. While the central bank is able to offset the nominal rigidity (namely the costs

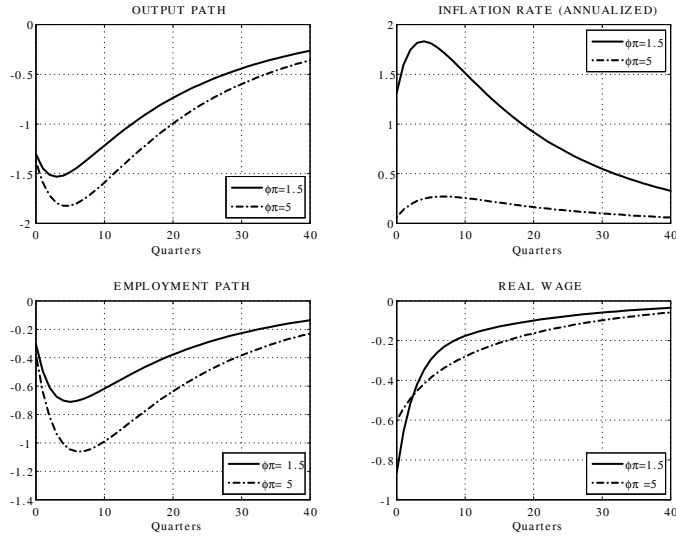


Figure 4: Model with Labor Turnover Costs

of sticky prices), it is unable to do so for the two real rigidities.

4.4 Model with RWRs and LTCs

When both labor market rigidities are combined (i.e., a model with RWRs and LTCs, calibrated as above), the impulse response functions are qualitatively very similar to the model with LTCs only (compare Figures 4 and 5). The reason for this is straightforward: In the LTCs model, wages are only one factor among many that determine the marginal costs. The expected future profits and the operating costs also affect the behavior of marginal costs (see Section 2.3). As a consequence, the behavior of real wages becomes less important and it has less of an effect than in the standard model, both on the impulse response functions and on the size of the tradeoff.¹⁴

¹⁴This finding is robust when we calibrate according to an Anglo-Saxon type of labor market. To be precise: As shown above I have assumed the firing costs to be 60 percent of the productivity. When this number is reduced to 10 percent and when the model is calibrated to generate quarterly job finding rates of around 70-80 percent and quarterly job destruction rates of 10 percent, LTCs continue to play the dominant role in generating the short-run inflation-output tradeoff.

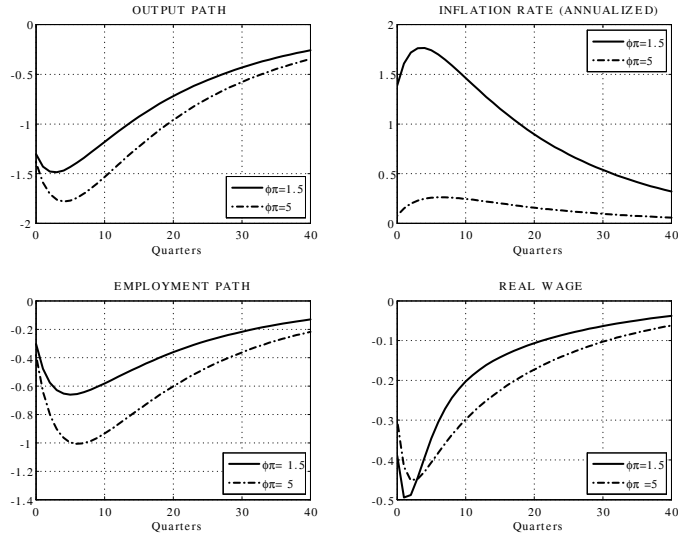


Figure 5: Model with Real Wage Rigidities and Labor Turnover Costs

5 Discussion

5.1 Some Theoretical Considerations

RWRs are specified in ad hoc manner in the literature (i.e., without deriving them explicitly from agents' optimizing behavior under a given labor market friction). Although sluggish wage adjustment patterns are visible in the aggregate data (more on this below), it is doubtful whether the RWRs specification that is chosen in the literature is stable with respect to different macroeconomic shocks (Lucas critique). Furthermore, RWRs are subject to the Barro critique. Barro (1977) pointed out that inflexible wage adjustments generate an efficiency loss. Agents would be likely to offset this loss by concluding long-term contracts.

LTCs are not subject to the same critiques. They are a ubiquitous feature of all labor markets, even when the LTCs which are imposed by government legislation are small or absent (e.g., through costs of screening or effort-related costs of labor turnover and productivity risk).

5.2 The Two Rigidities in Light of the Stylized Facts

While both types of labor market rigidity generate a nonnegligible short-run inflation output tradeoff between inflation and output stabilization, the impulse response functions (IRF) differ a lot. The IRFs for RWRs show some features that are difficult to reconcile with the empirical stylized facts. First, in the

theoretical simulation with RWRs (see Figure 3), the employment reaction under the hawkish rule turns from negative to positive (i.e., it shows an oscillatory pattern). While the employment reaction to productivity shocks is a hotly debated empirical issue,¹⁵ the oscillatory behavior of employment is at odds with the empirical evidence. Second, the inflation rate is less persistent in the aftermath of the shock with RWRs than without RWRs (compare speed of dying out of inflation in Figures 2 and 3). However, it is well known that the inflation persistence of the standard model is already too low. Thus, RWRs aggravate the existing problem.

In contrast, the model with LTCs generates persistent and hump-shaped employment, inflation and output responses (see Figure 4). The output and inflation persistence is higher than in both the standard model and the model with RWRs.¹⁶ Hiring and firing costs drive a wedge between the job finding rate, η , and the retention rate, $1 - \phi$,¹⁷ and make the labor market adjustment a lot more sluggish (see LMS for a more detailed explanation) than in the standard model. As a consequence, it takes a long time for the labor market to adjust and the sluggishness of the labor market is translated to all other markets. Therefore, the impulse response function of the model with LTCs is more in line with the empirical stylized facts than the model with RWRs is.

5.3 Empirical Underpinnings for the Two Rigidities

Looking at the data through macroeconomic spectacles suggests that there are indeed RWRs, as real wages behave more sluggishly than consumption and the labor input. Based on this macroeconomic view, Blanchard and Galí (2008) argue, for example, that RWRs were substantial in the United States during the 1970s, while they have been much lower during the 2000s. However, looking at the data through microeconomic spectacles suggests a different picture. There is empirical evidence¹⁸ that RWRs are relevant for current jobs in the United States but not for new jobs (Haefke et al., 2008). If this is true, RWRs become largely irrelevant for the inflation-output tradeoff. Tenhofen (2008) shows that RWRs for current jobs lead to substantially smaller inflation-output tradeoff than RWRs for all jobs.

The picture looks different when it comes to the empirical evidence for LTCs.

¹⁵Some authors find a negative employment reaction after positive productivity shocks (see, for example, Galí, 1999), while others find the opposite (see, for example, Dedola and Neri, 2007).

¹⁶The critical reader may object that LTCs generate a positive employment reaction, while many empirical studies show the opposite. There are two answers to this objection (i) this issue is not resolved in the empirical literature (see previous footnote), (ii) under lower autocorrelations for the productivity shock (e.g., $\rho = 0.8$), the LTC model generates a negative employment effect. While the Real Business Cycle literature typically uses very high autocorrelations (as is also done in this paper), the macro-labor literature uses much lower autocorrelations.

¹⁷The wedge between job finding rates and retention rates can be found in many microeconomic studies, in particular for continental European countries (for Germany, see, e.g., Wilke, 2005).

¹⁸Unfortunately, there is no evidence on this issue for European countries yet.

Their existence is widely documented across different OECD countries (see, e.g., Addison and Grosso, 1996, Botero et al., 2003, and OECD, 1999), although their magnitude is very different across countries and time. In most European countries, employment protection legislation was moderate during the 1960s, followed by a substantial rise during the 1970s and a small decline during the 1990s in some countries.¹⁹ In contrast to that, LTCs have remained relatively stable in most Anglo-Saxon countries (such as Australia, New Zealand, and the United States), although on a lower level than in Europe.

When countries in a monetary union have different RWRs or LTCs, this should result in different country-specific macroeconomic volatilities. However, Merkl and Schmitz (2009) show for the Eurozone that different degrees of RWRs do not have a clear-cut effect on the macroeconomic volatilities of different countries. In contrast, LTCs are shown to have a statistically and economically significant effect on output volatilities.

6 Conclusion

I have compared the effect of real wage rigidities and labor turnover costs in a monetary dynamic stochastic general equilibrium model. Both labor market rigidities generate an endogenous short-run inflation-output tradeoff. While the current focus of academic research rests very much on real wage rigidities, I have argued in this paper that attention should be shifted to the analysis of labor turnover costs.²⁰

¹⁹The picture is very similar for the conventionally used employment protection legislation indexes (see, e.g., Addison and Grosso, 1996, Addison and Teixeira, 2005, Blanchard and Wolfers, 2000, and OECD, 1999)

²⁰Recently, there has been substantial research on the effects of RWRs (see, e.g., Blanchard and Galí, 2007 and 2008, Christoffel and Kuester, 2008, Christoffel and Linzert, 2006, Faia, 2008, and Krause and Lubik, 2007), while the effect of LTCs on policy tradeoffs has been largely ignored (the only recent exceptions are Abbritti and Weber, 2008, and Faia et al., 2009).

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7 Technical Appendix

7.1 The Standard Model with RWRs

The model consists of the following equations:

$$\frac{1}{C_t^\sigma} = \beta E_t \left[\left(\frac{P_t}{P_{t+1}} \right) (1 + i_t) \left(\frac{1}{C_{t+1}^\sigma} \right) \right], \quad (12)$$

$$\frac{W_t}{P_t} = \left(\frac{W_{t-1}}{P_{t-1}} \right)^\gamma (N_t^\varphi C_t^\sigma)^{1-\gamma}, \quad (13)$$

$$\frac{P_{i,t}}{P_t} = \left(\frac{\varepsilon}{\varepsilon - 1} \right) \left(\frac{\psi_t}{\phi_t} \right), \quad (14)$$

$$\psi_t = u_c(t) Y_t \frac{W_t}{P_t A_t} + \theta \beta E_t (\pi_{t+1} \psi_{t+1}), \quad (15)$$

$$\phi_t = u_c(t) Y_t + \theta \beta E_t [\pi_{t+1}^\varepsilon \phi_{t+1}], \quad (16)$$

$$1 = \left[\theta \pi_t^{\varepsilon-1} + (1 - \theta) \left(\frac{P_{i,t}}{P_t} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}, \quad (17)$$

$$Y_t = C_t, \quad (18)$$

$$A_t N_t = s_t Y_t, \quad (19)$$

$$s_t = (1 - \theta) \left[\frac{P_{i,t}}{P_t} \right]^{-\varepsilon} + \theta \pi_t^\varepsilon s_{t-1}, \quad (20)$$

$$\left(\frac{1 + i_t}{1 + \bar{i}} \right) = \left(\frac{\pi_t}{\bar{\pi}} \right)^{\alpha_\pi} \left(\frac{Y_t}{\bar{Y}_t} \right)^{\alpha_y}, \quad (21)$$

$$A_t = A_{ss}^{1-\rho_a} A_{t-1}^{\rho_a} e^{\mu_t}. \quad (22)$$

7.2 The Model with LTCs

The model consists of the following equations:

$$\frac{1}{C_t^\sigma} = \beta E_t \left[\left(\frac{P_t}{P_{t+1}} \right) (1 + i_t) \left(\frac{1}{C_{t+1}^\sigma} \right) \right], \quad (23)$$

$$W_t/P_t = \zeta (A_t M C_t + S_t) + (1 - \zeta) B_t, \quad (24)$$

$$H = A_t M C_t - W_t/P_t - v_{h,t} + E_t(\Delta_{t,t+1} \tilde{\Pi}_{I,t+1}), \quad (25)$$

$$\eta_t = \Gamma(v_{h,t}), \quad (26)$$

$$-F = A_t M C_t - W_t/P_t - v_{f,t} + E_t(\Delta_{t,t+1} \tilde{\Pi}_{I,t+1}), \quad (27)$$

$$\phi_t = 1 - \Gamma(v_{f,t}), \quad (28)$$

$$E_t(\tilde{\Pi}_{I,t+1}) = E_t \left(\begin{array}{c} (1 - \phi_{t+1})(MC_{t+1}A_{t+1} - W_{t+1} - E_t(\varepsilon_{t+1}|1 - \phi_{t+1})) \\ + (1 - \phi_{t+1})E_{t+1}(\Delta_{t+1,t+2}\tilde{\Pi}_{I,t+2}) - \phi_{t+1}F \end{array} \right), \quad (29)$$

$$n_t = n_{t-1}(1 - \phi_t - \eta_t) + \eta_t, \quad (30)$$

$$\Xi_t^e = \frac{\int_{-\infty}^{v_h} \epsilon_t f(\epsilon_t) d\epsilon_t}{\eta_t}, \quad (31)$$

$$\Xi_t^i = \frac{\int_{-\infty}^{v_f} \epsilon_t f(\epsilon_t) d\epsilon_t}{1 - \phi_t}, \quad (32)$$

$$\frac{P_{i,t}}{P_t} = \left(\frac{\varepsilon}{\varepsilon - 1} \right) \left(\frac{\psi_t}{\phi_t} \right), \quad (33)$$

$$\psi_t = u_c(t) Y_t MC_t + \theta \beta E_t \left(\pi_{t+1}^\varepsilon \psi_{t+1} \right), \quad (34)$$

$$\phi_t = u_c(t) Y_t + \theta \beta E_t \left[\pi_{t+1}^{\varepsilon-1} \phi_{t+1} \right], \quad (35)$$

$$1 = \left[\theta \pi_t^{\varepsilon-1} + (1 - \theta) \left(\frac{P_{i,t}}{P_t} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}, \quad (36)$$

$$C_t = Y_t - n_{t-1} \phi_t F - (1 - n_{t-1}) \eta_t H - (1 - \phi_t) n_{t-1} \Xi_t^i - (1 - n_{t-1}) \eta_t \Xi_t^e, \quad (37)$$

$$n_t A_t = s_t Y_t, \quad (38)$$

$$s_t = (1 - \theta) \left[\frac{P_{i,t}}{P_t} \right]^{-\varepsilon} + \theta \pi_t^\varepsilon s_{t-1}, \quad (39)$$

$$\left(\frac{1 + i_t}{1 + \bar{i}} \right) = \left(\frac{\pi_t}{\bar{\pi}} \right)^{\alpha_\pi} \left(\frac{Y_t}{\bar{Y}_t} \right)^{\alpha_y} \quad (40)$$

$$A_t = A_{ss}^{1-\rho_a} A_{t-1}^{\rho_a} e^{\mu_t}. \quad (41)$$