Optimal Exchange Rate Flexibility with Large Labor Unions*

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Abstract

We study the optimal volatility of the exchange rate in a two-country model with sectoral non-atomistic wage setters, non-traded goods, nominal rigidities and alternative pricing assumptions – producer or local currency pricing. Labor unions internalize the sectoral impact of their wage settlements through firms' labor demand. With local currency pricing, an exchange rate depreciation raises sales revenue, which in turn boosts domestic consumption and labor demand. Unions anticipate this effect and set higher wages accordingly. With small unions and low wage markup, optimal monetary policy enhances exchange rate movements to improve its terms of trade. With large unions and high wage markup, optimal monetary policy curbs exchange rate movements to restrain inflationary wage demands and to stabilize employment.

JEL Classification: F3, F41, E52

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1 Introduction

Friedman (1953) celebrated the need for exchange rate flexibility in a world where nominal prices and wages adjust slowly. Under the assumption that the consumer home-currency price of imported goods changes one-to-one with the nominal exchange rate - commonly labeled producer currency pricing or PCP in the literature – flexible exchange rates cushion national economies from idiosyncratic shocks and allow rapid adjustment of relative prices even though nominal prices have not changed much. A large body of empirical evidence, however, suggests that the degree of exchange rate pass-through is far from complete in the short run and departures from the law of one price are large and persistent (see, for example, Engel and Rogers 1996, Goldberg and Knetter 1997, Campa and Goldberg 2005). When exchange rate fluctuations are not fully passed through to the user's currency price of imported goods - commonly labeled local currency pricing or LCP in the literature - deviations from the law of one price occur. Contrary to the PCP case, nominal exchange rate depreciation fails to make home-produced goods cheaper and to reallocate demand toward them; rather, it raises the foreign-currency revenues of foreign firms selling goods to the home economy at an unchanged home-currency price. As a result profits become more volatile and firms charge higher prices.

The evidence that exchange rate pass-through is incomplete has implications for the optimal exchange rate regime. Freely floating exchange rates may not be desirable because they lead to more volatile profits and thereby to higher prices. Corsetti and Pesenti (2005) and Devereux and Engel (2003) show that in the extreme case where exchange rate movements have no impact on consumer prices (predetermined prices) the optimal monetary regime is a pegged exchange rate. Duarte and Obstfeld (2008) and Corsetti (2006) note however that the optimality of fixed exchange rates under LCP rests on the perfect co-movement of consumption across countries due to the assumption of complete international asset markets and identical preferences. With non-traded goods or home bias, optimal monetary policies need not prescribe fixed exchange rates. Asynchronous international consumption responses call for exchange rate changes in the presence of nominal rigidities and pricing to market.

The debate on the optimal exchange rate regime with incomplete pass-through assumes that wage setters are atomistic. Whether labor markets are perfectly or monopolistically competitive, wages are chosen without taking into account how they will affect the aggregate wage and thereby the price level. Yet, sectoral labor unions are known to take into account aggregate economic conditions and to internalize the effects of their settlements; moreover they are a key feature of labor markets in many industrialized countries.[1] Considering sectoral, non-atomistic unions can enrich this debate. By raising the volatility of firms' profits, exchange rate flexibility affects the wage level asked by the union. Hence, optimal monetary policy directly affects the labor markup.

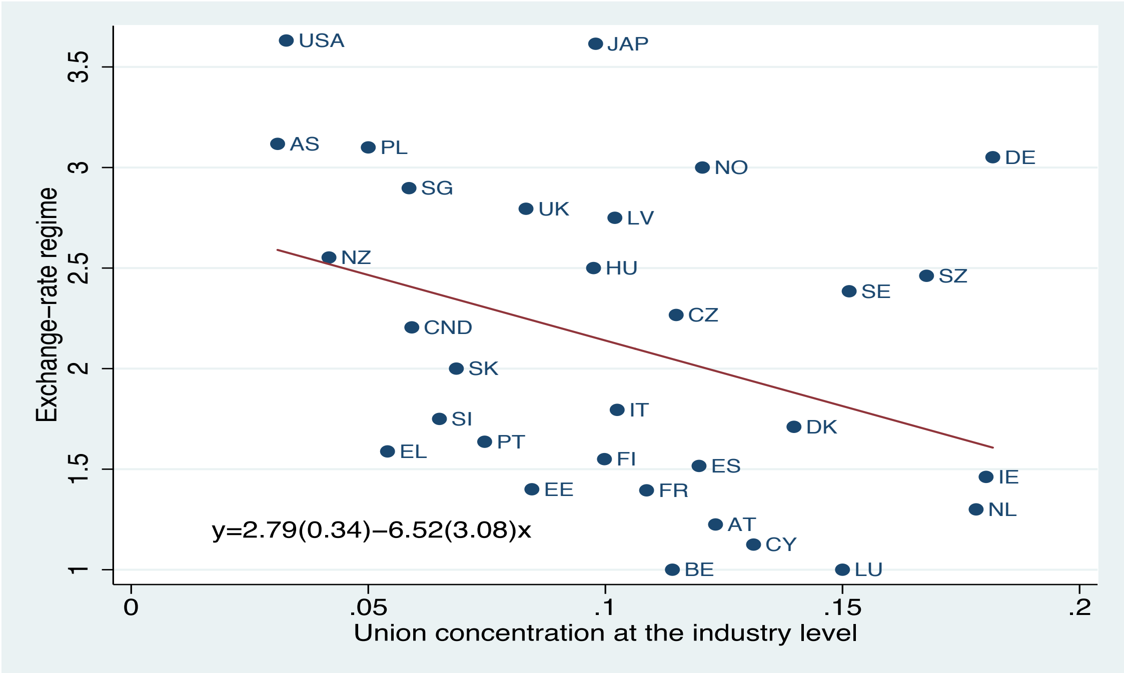
This paper studies optimal exchange rate flexibility in an analytically tractable New Open Economy Macroeconomic (NOEM) model with large labor unions. We draw on the analytical framework of Duarte and Obstfeld (2008) and maintain the presence of nontradable goods but allow for large sectoral unions, which are the focus of our analysis. We consider local and producer currency pricing. We find that optimal monetary policy is consistent with fully flexible exchange rates under PCP but not under LCP. LCP is not a rationale per se to peg the currency, but the presence of sectoral labor unions affects optimal exchange rate volatility relative to the case of atomistic wage setters. Few large unions reduce the optimal degree of exchange rate flexibility relative to the atomistic case; in the limiting case of a single sectoral union, it is optimal to fix the exchange rate even in the presence of nontraded goods. The intuition is as follows. Non-atomistic labor unions choose wages taking firms' labor demand as a constraint. Since an exchange rate depreciation raises profits and labor demand, unions demand a higher wage because they want to partake increased profits. Hence, flexible exchange rates lead to higher wages. In our environment optimal monetary policy faces a tradeoff under LCP. On one hand the presence of nontradable goods calls for exchange rate volatility, which pushes up wages and home prices and leads to an appreciated terms of trade; on the other hand, reduced exchange rate flexibility dampens wage demands and stabilizes marginal costs and hours worked. The latter effect dominates in the presence of few large unions and optimal exchange rate volatility is lower relative to the atomistic case. The former effects dominates only in the presence of a large number of non-atomistic unions and low wage markups; in this case optimal exchange rate volatility may increase relative to the atomistic case.

Figure 1 provides some suggestive evidence in the relationship between exchange rate flexibility and labor market concentration. Exchange rate regime is classified as follows: 1= De facto peg; 2= De facto crawling peg; 3= Managed floating; 4= Freely floating. Labor market concentration is measured as union concentration at the industry level. The data is for advanced economies over the period 1970 to 2010. Appendix D reports data sources and definitions. A simple linear regression suggests that countries characterized by higher union

[1] See the evidence in Nickell, Nunziata, and Ochel (2005) and Du Caju, Gautier, Momferatou, and Ward-Warmedinger (2009).

concentration exhibit lower exchange rate flexibility.[2]

Figure 1: Exchange rate regime and concentrated labor markets



Note: Union concentration at industry level denotes the membership concentration within confederations (Herfindahl index at sectoral level). This variable measures the proportion of total membership organized by the x-th affiliate. Standard errors in parentheses. *Sources:* ICTWSS dataset and Ilzetzki, Reinhart, and Rogoff (2008)

The outline of the paper is as follows. Section 2 connects our paper and its contribution to the existing literature. Section 3 presents the model and section 4 focuses on the wage setting decision. Section 5 analyzes optimal monetary policy and section 6 concludes.

2 Related literature

This paper is related to several strands of the literature. Theoretical studies document that a fixed exchange rate is not optimal with LCP if one introduces home bias in consumption

[2]We performed two robustness checks. First, we eliminated the Euro Zone countries, which experienced a clear structural break. Second, we considered all countries but limited the sample to the period 1970 to 1998. In both cases the negative relationship between exchange rate flexibility and union concentration was confirmed; in the first case the coefficient in the linear regression was -6.02 (significant at the 6% level) and in the second case the coefficient was -6.82 (significant at the 3% level).

(e.g. Devereux and Engel 2003, Corsetti and Pesenti 2005, Duarte and Obstfeld 2008). This may be the case also in a fully-fledged New Keynesian dynamic stochastic model which incorporates standard Calvo sticky prices (see Engel 2011). In particular, Engel (2011) focuses on the case of simple algebraic characterizations of the optimal targeting rules under LCP by assuming a linear disutility of labor and unitary elasticity of substitution between domestic and foreign goods. Here, in line with the standard NOEM approach, we also concentrate on the case in which preferences are linear in leisure and Cobb-Douglas over an aggregate of home-produced and foreign-produced goods.[3] However, we find that LCP can be a reason to peg the currency in the Duarte and Obstfeld (2008) setup, when there is a single sector-wide union bargaining over the wage for that sector.[4] In general, monetary authorities have a stronger incentive to reduce exchange rate flexibility when there are a few unions in each sector than in the case with atomistic wage setters.

Besides adding to the NOEM literature, our paper contributes to a vast literature on non-atomistic wage-setting in corporatist economies in which large unions internalize the inflationary effect of their wage decisions (see e.g. Bruno and Sachs 1985, Tarantelli 1986, Calmfors and Driffill 1988). Several works have extended these theoretical insights to an open economy setup, mainly focussing on the strategic interaction between monetary policy and wage setting.[5] We model large unions as in Vartiainen (2002) and Holden (2003) and embed them in a two-country model with price and wage stickiness. Our departure from this literature is to perform an analytically tractable NOEM with varying degrees of price rigidity and to allow for LCP.

Finally, our paper is also related to the empirical literature that studies the role of labor market institutions in order to explain the different response of wages to shocks in the United States and European countries (Blanchard and Wolfers 2000, Bertola, Blau, and Kahn 2002).

[3]See Corsetti, Dedola, and Leduc (2010) for a survey on the role of local currency pricing in a NOEM model with more general preference parameters.

[4]This special case can be conceptualized as large bargaining cartels or coordination between unions at the sector level. Note that these types of sectoral wage agreements have been implemented in most Western European countries (such as Denmark, Sweden, Germany, Austria, Switzerland, the Netherlands, and Italy) at different points in time.

[5]See e.g. Jensen (1993), Soskice and Iversen (1998), Grüner and Hefeker (1999), Cukierman and Lippi (2001), Cavallari (2001), Coricelli, Cukierman, and Dalmazzo (2004), Acocella, Di Bartolomeo, and Tirelli (2007), Cuciniello (2011, 2013).

3 The model setup

The model follows Duarte and Obstfeld (2008) with the addition of sectoral unions and nominal wage rigidities. The economy consists of two ex-ante equally-sized countries, Home and Foreign, inhabited by a continuum of households (with population size normalized to 1) and a finite number of unions. In monopolistic competitive markets, domestic firms produce tradable and nontradable goods. Production of the Home (Foreign) goods requires a continuum of differentiated labor inputs.

3.1 Households

Preferences of the representative Home agent $z \in [0, 1]$ are defined over consumption C and labor supplied $L = L_N + L_H$:

$$U_t(z) = \log C_t(z) - kL_t(z). \tag{1}$$

For any person z the overall consumption index C is a Cobb-Douglas aggregate of the tradable and nontradable composite goods given by

$$C = \frac{C_T^{\gamma} C_N^{1-\gamma}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}} \qquad 0 < \gamma < 1, \tag{2}$$

where the tradable goods subindex C_T is $C_T = 2C_H^{1/2} C_F^{1/2}$. C_H, C_F and C_N are CES aggregators of respectively Home-produced and Foreign-produced traded varieties and Home-produced non-traded varieties,

$$C_j = \left[\int_0^1 C_j(i)^{\frac{\theta-1}{\theta}} \mathrm{d}i \right]^{\frac{\theta}{\theta-1}} \qquad \theta > 1, \qquad j \in \{H, F, N\}.^{6}$$

The consumption-based price index expressed in domestic currency is defined as $P = P_T^{\gamma} P_N^{1-\gamma}$, with $P_T = P_H^{1/2} P_F^{1/2}$ and

$$P_j = \begin{cases} \left[\int_0^1 P_j(i)^{1-\theta} \mathrm{d}i \right]^{\frac{1}{1-\theta}}, & j \in \{H, N\} \\ \left[\int_1^2 P_j(i)^{1-\theta} \mathrm{d}i \right]^{\frac{1}{1-\theta}}, & j = F. \end{cases}$$

[6] For traded goods produced in the Foreign country, i.e. $j = F$, the integration is over the interval [1,2].

Each z-th individual trades state-contingent nominal bonds denominated in the Home currency. We denote the price at date t when the state of the world is s_t of a bond paying one unit of Home currency at date $t+1$ if the state of the world is s_{t+1} by $Q_{s_{t+1}|s_t}$. The quantity of these bonds purchased by the Home agent z at date t is $B_{s_{t+1}}$, while revenues received at date t when the state of the world is s_t are denoted by B_{s_t}. Firm's profits are entirely redistributed as dividends among domestic agents.

A typical Home agent z faces the following budget constraint in nominal terms

$$\begin{aligned} P_t C_t(z) + M_t(z) + \sum_{s_{t+1}} Q_{s_{t+1}|s_t} B_{s_{t+1}}(z) &= B_{s_t}(z) + T_t(z) + M_{t-1}(z) + \Pi_t(z) + \\ &\int_0^1 [W_{Ht}(z) L_{Ht}(i,z) + W_{Nt}(z) L_{Nt}(i,z)] \mathrm{d}i, \end{aligned} \quad (3)$$

where $W_j(z)L_j(i,z)$ denotes labor income received from firm i operating in sector $j \in \{H, N\}$, $\Pi(z)$ indicates nominal dividends received from domestic firms and $T(z)$ are per capita lump-sum transfers from the Home government.[7] Nominal wage stickiness would generate heterogeneity in terms of labor income across Home agents. For this reason we assume there is perfect insurance so that labor income is ex-post equal across all Home households. Individuals take firm behavior and lump-sum transfers as given.

We introduce money into the model by means of a cash-in-advance constraint:[8]

$$P_t C_t(z) \leq M_t(z). \quad (4)$$

As the purchasing-power-parity condition need not hold in the model, the marginal utilities of consumption are not necessarily equated between countries:

$$\frac{C_t(z)}{C_t^*(z^*)} = \frac{C_t}{C_t^*} = \frac{\mathcal{E}_t P_t^*}{P_t}, \quad (5)$$

where $\mathcal{E}$ is the exchange rate expressed as domestic price of foreign currency. Foreign households (with * denoting Foreign variables) are modeled in an analogous way.

[7] Seignorage revenue is rebated to households through lump-sum transfers: $\int_0^1 (M_t(z) - M_{t-1}(z))\mathrm{d}z = \int_0^1 T_t(z)\mathrm{d}z$.

[8] Our analysis can be easily generalized to a setup with real money balances in the utility function without affecting the results of the paper.

3.2 Firms

The optimal intra-temporal allocation of consumption of Home and Foreign traded varieties and the non-traded varieties yields the following demands for the i-th domestic firm:

$$C_H(i) = \frac{\gamma}{2}\left(\frac{P_H(i)}{P_H}\right)^{-\theta}\left(\frac{P_H}{P_T}\right)^{-1}\left(\frac{P_T}{P}\right)^{-1} C, \tag{6}$$

$$C_H^*(i) = \frac{\gamma}{2}\left(\frac{P_H^*(i)}{P_H^*}\right)^{-\theta}\left(\frac{P_H^*}{P_T^*}\right)^{-1}\left(\frac{P_T^*}{P^*}\right)^{-1} C^*, \tag{7}$$

$$C_N(i) = (1-\gamma)\left(\frac{P_N(i)}{P_N}\right)^{-\theta}\left(\frac{P_N}{P}\right)^{-1} C. \tag{8}$$

Let $Y_j(i)$ denote the level of output produced by the monopolistically competitive firm i and supplied to the Home tradable market ($j = H$) or to the Home nontradable market ($j = N$). Technology is described by the following production function:

$$Y_{jt}(i) = A_t L_{jt}(i), \qquad j \in \{H, N\}, \tag{9}$$

where A is an economy-wide productivity shock,

$$\log A_t = \log A_{t-1} + u_t, \tag{10}$$

and u is a normally distributed shock with mean zero and variance σ_u^2. $L_j(i)$ indicates the labor index defined as a Dixit-Stiglitz aggregate of the differentiated labor types:[9]

$$L_{jt}(i) = \left[\int_0^1 L_{jt}(i,z)^{\frac{\sigma-1}{\sigma}} \mathrm{d}z\right]^{\frac{\sigma}{\sigma-1}}, \qquad j \in \{H, N\}, \qquad \sigma > 1. \tag{11}$$

For a given level of production, demand for labor type z by producer i solves the dual problem of minimizing total cost, $\int_0^1 W_j(z) L_j(i,z)\mathrm{d}z$, subject to the employment index (11):

$$L_{jt}(i,z) = \left[\frac{W_{jt}(z)}{W_{jt}}\right]^{-\sigma} L_{j,t}(i), \qquad j \in \{H, N\}, \tag{12}$$

where $W_j(z)$ denotes the nominal wage of labor type z in sector j and W_j is the nominal

[9] A symmetric production function holds in the Foreign country with the productivity shock $\log A_t^* = \log A_{t-1}^* + u_t^*$, where u_t^* is a normally distributed shock with mean zero and variance $\sigma_{u^*}^2$.

wage index in sector j defined as

$$W_{jt} = \left[\int_0^1 W_{jt}(z)^{1-\sigma}\mathrm{d}z\right]^{\frac{1}{1-\sigma}}, \qquad j \in \{H, N\}. \tag{13}$$

Aggregate labor demand for labor type z is found by integrating (12) over all producers to obtain

$$L_{jt}(z) = \int_0^1 \left[\frac{W_{jt}(z)}{W_{jt}}\right]^{-\sigma} L_{jt}(i)\ \mathrm{d}i\ = \left[\frac{W_{jt}(z)}{W_{jt}}\right]^{-\sigma} L_{jt}, \qquad j \in \{H, N\}. \tag{14}$$

We assume that prices are partially (or fully) predetermined before productivity shocks are realized. More precisely, the Home price of Home varieties is equal to

$$P_{jt} = \bar{P}_{jt}^{1-\tau}\left[\mathcal{M}_p \frac{W_{jt}}{A_t}\right]^{\tau}, \qquad j \in \{H, N\}, \tag{15}$$

while the Foreign price of Home traded varieties is

$$P^*_{Ht} = (\bar{P}^*_{Ht})^{1-\tau}\left[\mathcal{M}_p \frac{W_{Ht}}{\mathcal{E}_t A_t}\right]^{\tau}, \tag{16}$$

where $(1-\tau) \in [0,1]$ is the degree of price stickiness. When $\tau = 0$ all prices are predetermined; on the other hand, when $\tau = 1$ prices are flexible and can be adjusted after productivity shocks are realized. For $\tau \in (0,1)$ only a fraction of prices is flexible and can be adjusted after shocks are realized.[10] Accordingly, a $^{-}$ denotes the price set before productivity shocks are realized; the term in square brackets is the flexible price, namely the price chosen after productivity shocks are realized. $\mathcal{M}_p \equiv \theta/(\theta-1)$ is the price markup under imperfect competition.

For the price of tradable goods chosen one period in advance, we consider two different price-setting specifications: local currency pricing (LCP) and producer currency pricing (PCP). Under LCP producers set prices in the customer's currency. This implies that the Home variety i is sold at $\bar{P}_H(i)$ to Home consumers but at $\bar{P}^*_H(i)$ to Foreign consumers. On the other hand, under PCP all tradable goods are priced in the producer's currency. Formally, firm i operating in the traded goods sector chooses $\bar{P}_{Ht}(i)$ and $\bar{P}^*_{Ht}(i)$ so as to

[10] This is a discrete-time variant of the Calvo price-setting mechanism. More precisely, we assume that all prices can be freely set at the beginning of the period ($\bar{P}_{jt}$) but only a fraction τ can be adjusted after the shocks are realized. Hence, following a temporary but persistent shock at time t, a fraction τ of prices can instantaneously adjust while the remaining $(1-\tau)$ prices will adjust at the beginning of period $t+1$.

maximize expected discounted profits

$$\max \mathrm{E}_{t-1} d_{t-1,t}\left[\bar{P}_{Ht}(i)C_{Ht}(i)+\mathcal{E}_t\bar{P}^*_{Ht}(i)C^*_{Ht}(i)-\frac{W_{Ht}}{A_t}(C_{Ht}(i)+C^*_{Ht}(i))\right], \tag{17}$$

subject to the demand functions (6) and (7). $d_{t-1,t}\equiv\beta C_{t-1}P_{t-1}/(C_tP_t)$ is the pricing kernel between $t-1$ and t. Home firms producing non-traded goods choose a single price in domestic currency and their maximization problem is similar to that of Home firms selling traded goods in the domestic market.

Consider first domestic price setting. The optimal price of Home producers of tradable and nontradable goods sold in the Home market is

$$\bar{P}^{PCP}_{jt}=\bar{P}^{LCP}_{jt}=\mathrm{E}_{t-1}\left[\mathcal{M}_p\frac{W_{jt}}{A_t}\right] \qquad j\in\{H,N\}. \tag{18}$$

Preset domestic prices are equal to a markup over expected marginal costs. Conversely, the optimal price for tradable goods sold in the Foreign market under PCP and LCP are respectively

$$\bar{P}^{*PCP}_{Ht}=\bar{P}^{PCP}_{Ht}/\mathcal{E}_t, \tag{19}$$

$$\bar{P}^{*LCP}_{Ht}=\mathrm{E}_{t-1}\left[\mathcal{M}_p\frac{W_{Ht}\mathcal{E}_t^{-1}}{A_t}\right]. \tag{20}$$

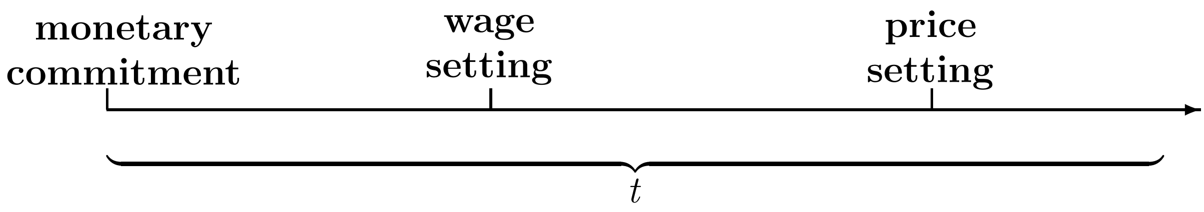
3.3 Timing and Monetary Policy

In each period unions set wages, then firms choose prices and determine employment. We allow for an arbitrary degree of wage stickiness. Specifically, a fraction $1-\nu$ of wages is set before shocks are realized and kept unchanged until the end of the period. The remaining fraction ν of wages can be adjusted after the realization of shocks.

The monetary authority in the Home country commits to a preannounced state-contingent monetary rule of the following type:

$$\widehat{m}_t=m_t-\mathrm{E}_{t-1}m_t, \tag{21}$$

where, for any variable X, we define $x\equiv\ln X$ and $\widehat{x}_t\equiv x_t-\mathrm{E}_{t-1}x_t$ for innovations in x_t. The Foreign monetary authority commits to a similar rule. The timing of events is summarized below.



4 Wage setting

Each sector is organized in $n > 1$ labor unions that negotiate wages on behalf of their members. All workers are unionized and equally distributed among unions. Union size is $1/n$; larger unions represent more workers and better internalize the consequences of their demands on aggregate sectoral wage. Provided the representative labor union has a finite mass,[11] it anticipates that

$$\frac{\partial W_j}{\partial W_j(x)}\frac{W_j(x)}{W_j} = \frac{\partial W_j}{\partial W_j(x)} = \frac{1}{n}, \qquad j \in \{H, N\}, \tag{22}$$

in a symmetric Nash equilibrium with $W_j(x) = W_j$ – see Appendix A. A lower n implies fewer but larger unions that anticipate a stronger pass-through of their own wage demands on aggregate wage. Atomistic unions ($n \to \infty$), on the other hand, anticipate *no* effect of an increase in their own wage on the aggregate wage. The fact that unions internalize the impact of their actions on aggregate variables generates static and dynamic effects.[12] To better understand these effects, we analyze first the case of flexible price and wage setting.

4.1 Flexible prices and wages ($\tau = \nu = 1$)

The representative labor union chooses wage for its member workers, who supply as many hours as firms demand at that wage. In any period t the x-th union in sector j chooses the nominal wage $W_{jt}(x)$ taking monetary policy as given. Following Benigno and Woodford (2005) the union maximizes

$$V_{jt}(x) = n\int_{z\in x} \left[\Lambda_t W_{jt}(x)L_{jt}(z) - kL_{jt}(z)\right] \mathrm{d}z, \qquad j \in \{H, N\}, \tag{23}$$

[11]Namely, as long as $\int_{z\in x} \mathrm{d}z = 1/n > 0$.

[12]Aidt and Tzannatos (2008) reviews the literature on the static and dynamic effects of bargaining coordination in the labor market.

subject to the labor demand (14) and the optimal price setting (15). Λ_t is the representative household's marginal utility of nominal income in period t. The assumption that the union maximizes (23) rather than the utility function of the agent simplifies the wage markup expression without affecting the main mechanisms at play in the wage setting process (see discussion below). Appendix B shows that, in a symmetric equilibrium, the first-order condition with respect to $W_{jt}(x)$ yields

$$\frac{W_{jt}}{P_t} = k\mathcal{M}_w C_t, \qquad j \in \{H, N\}. \tag{24}$$

The real wage is a constant markup over the marginal rate of substitution between consumption and leisure where the markup is

$$\mathcal{M}_w \equiv \frac{\Sigma}{\Sigma - 1} = 1 + \frac{n}{(n-1)(\sigma-1)}, \tag{25}$$

where

$$\Sigma \equiv \left| \frac{\partial \log L_j(x)}{\partial \log W_j(x)} \right| = \sigma \left(1 - \frac{1}{n}\right) + \frac{1}{n}, \qquad j \in \{H, N\} \tag{26}$$

is the wage elasticity of labor demand *perceived* by the union.

The presence of non-atomistic labor unions yields a higher (relative to the atomistic case) markup that increases with the union's size, $1/n$. When wage setters are atomistic $\mathcal{M}_w = \sigma/(\sigma - 1)$; as n falls the markup increases. Large unions increase the bargaining power of workers and thereby the equilibrium wage.[13]

Appendix B shows that the wage elasticity of aggregate labor demand is equal to $1 < \sigma$. If all wages are simultaneously increased, the aggregate labor demand response for a single worker is smaller than it would be if that worker raised her wage unilaterally. Hence, atomistic wage setters overestimate the wage elasticity of labor demand from a national perspective. By internalizing the correct wage elasticity, non-atomistic wage setters reinforce their monopoly power in the labor market. The wage elasticity of labor demand (26) perceived by the union is a weighted average of the elasticity of substitution among labor types (equal to σ) and the elasticity of aggregate labor demand (equal to 1) with weights $1 - 1/n$ and $1/n$, respectively. In fact, concentrated labor markets affect wages through two channels. First, they reduce wage differentials among labor types. This dampens firm's substitution effect, thereby reducing the labor demand elasticity perceived by the union. Second, unions

[13] The role of trade unions in boosting bargaining power and wage premium is largely documented (e.g. Booth 1995, Boeri and van Ours 2008).

internalize the effect of their wage claims on aggregate labor demand to a larger extent.

In our model the wage markup does not depend on the incentive to improve the terms of trade. This is a direct result of the assumption that the labor union maximizes the utility functional (23) rather than (1): the former entails taking the marginal utility of nominal income as given. Relaxing this assumption would not affect the main results of paper, but would lead to different wage markups in the tradable and nontradable sector. Specifically, there would be an additional consumption effect inducing inflationary wage demands in the tradable and nontradable sector stemming respectively from an increase in P_H/P and P_N/P.[14]

Using (24) and the corresponding expression for Foreign wages we find that total consumption depends only on productivity shocks

$$C_t^{flex} = \frac{(A_t^*)^{\gamma/2} A_t^{1-\gamma/2}}{k\mathcal{M}} \tag{27}$$

and labor effort is constant

$$L_t^{flex} = \frac{1}{k\mathcal{M}}, \tag{28}$$

where $\mathcal{M} \equiv \mathcal{M}_p \mathcal{M}_w$. Consumption and labor are independent of monetary policy with flexible wages and prices. A Home productivity shock raises total consumption more in the Home country than in the Foreign one. Wage innovations are

$$\widehat{w}_{Nt} = \widehat{w}_{Ht} = \widehat{m}_t. \tag{29}$$

From equations (4) and (5), we recover exchange rate innovations:

$$\widehat{\varepsilon}_t = \widehat{m}_t - \widehat{m}_t^*. \tag{30}$$

4.2 Partial adjustment of prices and wages ($\tau, \nu \in (0, 1)$)

We now consider the case where a fraction $1 - \tau$ of prices and $1 - \nu$ of wages is fixed before shocks are realized and cannot be adjusted. The remaining fraction τ of prices and ν of

[14] An increase in P_j/P drives up the relative real wage of sector j workers and produce a "beggar-thy-neighbor" welfare spillover: the burden of labor input production switches from sector j to other sectors. However, consumption of goods switches from good j to the other goods as well. Because of this consumption-switching, the union markup would be decreasing in the degree of openness γ in the tradable sector while increasing in the nontradable sector, as for instance in Holden (2003). Cuciniello (2013) identifies the role of the international consumption-switching effect on the wage markup in a model with large labor unions.

wages is chosen after uncertainty has realized. Unions set wages before firms hire labor and produce.[15] Specifically, if union x can choose its wage after shocks have realized, it maximizes the welfare of its members (23) with respect to $W_{jt}(x)$ subject to the labor demand (14), the budget constraint (3) and the optimal price setting (15), taking monetary policy as given. On the other hand, if union x must set its wage before shocks have realized, it maximizes expected (as of time $t-1$) welfare of its members subject to expected shock and variable realizations. The details of the derivations are relegated to Appendix B. In a symmetric equilibrium $W_{jt}(x) = W_{jt}$ for $j = H, N$, we obtain that

$$\widehat{w}_{Nt} = \nu \left\{ \Psi \widehat{m}_t + (1-\Psi) u_t \right\}, \tag{31}$$

and

$$\widehat{w}_{Ht}^{PCP} = \widehat{w}_{Nt} \qquad\qquad \widehat{w}_{Ht}^{LCP} = \widehat{w}_{Nt} + \nu(1-\Psi)\widehat{\varepsilon}_t/2, \tag{32}$$

where $\mathcal{M}_w$ is the static wage markup defined by (25) and

$$\Psi \equiv \frac{1+\sigma(n-1)}{(1-\tau)\mathcal{M}_w + \sigma(n-1) + \tau} \in (0,1). \tag{33}$$

With nominal rigidities, non-atomistic labor unions affect the intensity of the wage response to productivity and exchange rate innovations. Wage innovations for non-traded and traded goods under PCP are a weighted average of monetary ($\widehat{m}_t$) and productivity (u_t) innovations with weights equal to Ψ and $1-\Psi$, respectively. A higher degree of centralization in wage bargaining, namely a lower number of unions n, decreases the weight Ψ attached to the response to monetary policy and increases the weight attached to the response to productivity shocks, thereby shifting unions' concern from nominal to real shocks.[16] A positive monetary innovation expands aggregate demand. Everything else equal, nominal wages increase through a shift in the labor demand curve because predetermined price firms want to adjust quantities and produce more.

Under LCP unions in charge of setting wages in the tradable good sector respond directly

[15]Earlier contributions to the literature on non-atomistic wage setters (e.g. Calmfors and Driffill 1988, Cubitt 1992) consider the case where unions can use and commit to closed-loop strategies. We do not follow this assumption here.

[16]Formally, we can differentiate (33) with respect to n:

$$\frac{\partial \Psi}{\partial n} = \frac{(\sigma-1)\left[1+\left(n^2-1\right)\sigma\right](1-\tau)}{\left[1+(n-1)(2+n(\sigma-1)-\sigma)\sigma - n\tau\right]^2} > 0.$$

to exchange rate innovations. The intuition for these results is as follows. For given prices and wages, a positive productivity shock reduces the marginal cost of firms and raises profits in both sector. If firms cannot adjust their price, labor unions can reap some of the benefits of higher profits through their wage decisions. This is why the optimal wage response to a productivity shock prescribes a less-than-proportional increase in wages. The same intuition applies to an innovation in the exchange rate. Following a depreciation of the nominal exchange rate, firms producing tradable goods priced in Foreign currency experience an increase in sale revenues and profits. It is the anticipation of higher profits triggered by higher productivity or an exchange rate depreciation to induce sectoral unions to set higher wages.

Expressions (31) and (32) show how centralized wage setting influences the optimal wage response to both nominal and real shocks. This result adds to the literature on the role of labor market institutions to explain the different response of wages to shocks in the United States and European countries (Blanchard and Wolfers 2000, Bertola, Blau, and Kahn 2002). Furthermore, it provides new insight into the role of exchange rate pass-through and labor market institutions under nominal wage rigidities.[17]

5 Optimal monetary policy and exchange rate flexibility

We study optimal monetary policy when the monetary authority can commit to the rule (21).[18] Our goal is to assess the effect of centralized wage bargaining on optimal monetary responses and exchange rate flexibility. We show that, under optimal policy making, exchange rate flexibility depends on the exchange rate pass-through and the degree of centralization of wage setting.

Let U_t^{flex} denote utility of the representative Home agent under flexible prices and wages; a similar expression holds for the representative Foreign agent. As in Corsetti and Pesenti (2005), the monetary authority in each country maximizes the gap between resident house-

[17]Some recent contributions focus on the impact of exchange rate depreciation on wage dynamics and inflation. This channel is clearly accounted for by the model. In Campolmi and Faia (2009), for example, nominal exchange rate depreciations are fully passed through to goods prices, because of the presence of a *real wage wedge*. In our model also *nominal* wages are affected by exchange rate fluctuations under LCP.

[18]Our interest in rule-based monetary policy making is motivated by its growing importance in practice as well as in academic circles.

hold's expected utility with and without nominal rigidities:

$$\mathrm{E}_{t-1}\mathcal{U}_t \equiv \mathrm{E}_{t-1}\left\{U_t^{flex} - U_t\right\}. \tag{34}$$

The monetary authority at Home maximizes (34) with respect to $\widehat{m}_t$ taking $\widehat{m}_t^*$ as given and anticipating the wage setting decision of Home unions. The Foreign monetary authority solves the symmetric problem.

Without loss of generality, we assume the existence of a production subsidy that fully offsets the distortion from monopolistic competition in the goods market, i.e. $\mathcal{M}_p/(1+\xi) = 1$. This allows us to isolate the influence of product market monopolistic distortions on the conduct of monetary policy.

5.1 Predetermined prices and flexible wages ($\tau = 0, \nu = 1$)

To compare our findings with those in the literature, we consider first the case where prices are fully predetermined ($\tau = 0$) and wages fully flexible ($\nu = 1$). Appendix C shows that optimal monetary is

$$\widehat{m}_t^{PCP} = u_t, \qquad\qquad \widehat{m}_t^{LCP} = \Xi u_t + \Theta u_t^*, \tag{35}$$

where

$$\Xi \equiv \frac{2-\gamma}{2(1-\gamma)}\left(1 - \frac{\gamma(1+(3-2\gamma)\Psi)}{(2-\gamma)\left(\gamma+(4-3\gamma)\Psi-2(1-\gamma)\Psi^2\right)}\right) \in (0,1],$$

$$\Theta \equiv \frac{\gamma}{2(1-\gamma)}\left(\frac{1+(3-2\gamma)\Psi}{\gamma+(4-3\gamma)\Psi-2(1-\gamma)\Psi^2} - 1\right) \in [0,1) \qquad \text{and} \qquad \Xi > \Theta.$$

Substituting optimal monetary policy into (30) we find that the conditional variance of the exchange rate is given by

$$\mathtt{var}_{t-1}(\widehat{\varepsilon}_t^{PCP}) = \sigma_u^2 + \sigma_{u^*}^2 \tag{36}$$

under PCP and by

$$\mathtt{var}_{t-1}(\widehat{\varepsilon}_t^{LCP}) = \left[\frac{2\Psi(2-\gamma-\Psi)}{\gamma+(4-3\gamma)\Psi-2(1-\gamma)\Psi^2}\right]^2(\sigma_u^2 + \sigma_{u^*}^2) \tag{37}$$

under LCP.

Under PCP optimal monetary policy responds one-to-one to real domestic shocks to stabilize Home firms' marginal costs. This is the "inward-looking" outcome in Clarida, Gali, and Gertler (2001). Optimal monetary policy generates exchange rate movements that reproduce the flexible price allocation under PCP. Non-atomistic wage setters do not generate any tradeoff for monetary policy, since they primarily react to changes in productivity. Marginal cost and employment volatilities are thus smaller relative to the case of atomistic wage setters.[19] An increase in productivity lowers firms' marginal costs, increasing markups and profits. As a result, domestic consumption increases as well as labor demand and production. If labor unions can adjust their wages, they are induced to set higher wages because they anticipate an increase in labor demand. Hence, sectoral unions stabilize marginal costs, employment and prices, reinforcing the efficacy of monetary stance in achieving flexible price allocation.

The case of $n \to 1$

Taking the limiting case where all wages are effectively determined by a single sectoral union (namely centralized wage bargaining at the sector level: $n \to 1$ so that $\Psi \to 0$), employment is at its flexible-price level. It turns out that monetary policy can focus completely on consumption and reduce exchange rate volatility under LCP. In this case, efficient stabilization implies a fixed exchange rate even in the presence of nontradable goods,

$$\mathtt{var}_{t-1}(\widehat{\varepsilon}_t^{LCP}) = 0. \tag{38}$$

The case of $n \to \infty$

Our framework encompasses, as special case, an open economy with atomistic wage setters and nontradable goods (as in Duarte and Obstfeld 2008). In this case, optimal Home monetary policy under LCP becomes

$$\widehat{m}_t^{LCP}\Big|_{n\to\infty} = \left(1 - \frac{\gamma}{2}\right) u_t + \frac{\gamma}{2} u_t^*,$$

and the exchange rate volatility is given by

$$\mathtt{var}_{t-1}(\widehat{\varepsilon}_t^{LCP}) = [1-\gamma]^2 \left(\sigma_u^2 + \sigma_{u^*}^2\right). \tag{39}$$

[19] Theoretical contributions and empirical evidence suggest that the cyclical volatility of employment is more pronounced in the relatively less regulated labor markets, such as Anglo-Saxon countries, than in Continental Europe (e.g. Bertola and Ichino 1995, OECD 2009, Veracierto 2008, Elsby, Hobijn, and Sahin 2011).

The equation above simply replicates the Duarte and Obstfeld (2008) result: the optimal exchange rate volatility depends only on the presence of nontradable goods. The presence of home bias in consumption (due to nontradable goods $\gamma < 1$) lies at the core of the asymmetric monetary response to shocks in either country. When $\gamma = 1$ Home and Foreign agents consume the same basket of goods and exchange rate flexibility is not optimal as in Devereux and Engel (2003).

The Home monetary authority partially accommodates domestic real shocks to stabilize firms' marginal costs. But, in doing that, it boosts domestic demand, depreciates the exchange rate, and lowers the revenues of Foreign firms. The latter effect creates a link between domestic monetary policy and Foreign firms, which react to lower profits by charging higher prices for their products sold in the Home country. Similarly, a Foreign productivity shock triggers a monetary expansion abroad, which generates an appreciation of the exchange rate, a decrease in Home firms' revenues, and thus lower dividend incomes. Home policymakers face a tradeoff between stabilizing the marginal revenues of domestic producers by expanding money supply so that the exchange rate appreciates less and keeping import prices low.

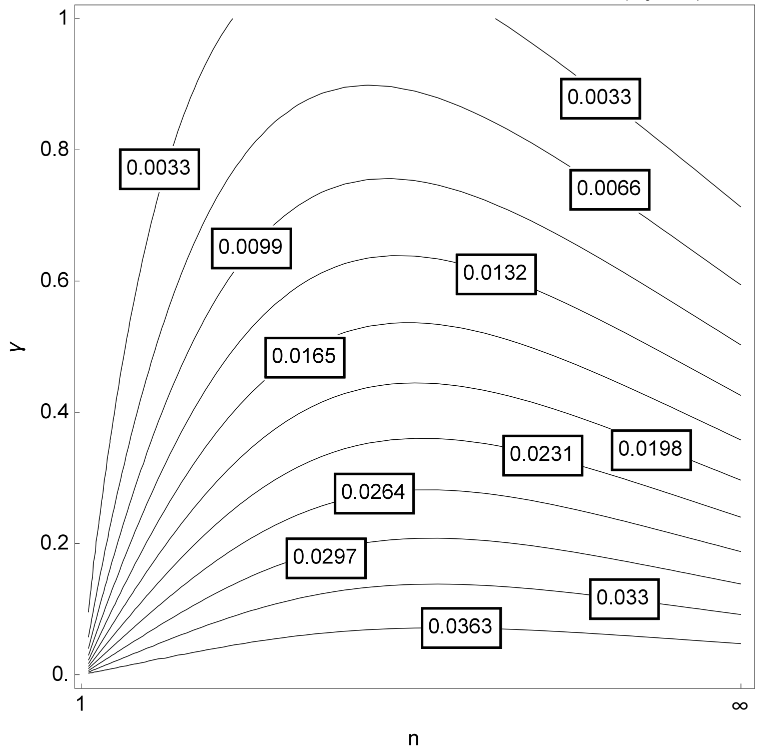
The case of $1 < n < \infty$

Figure 2 plots equation (37) for $n > 1$ setting $\sigma_u^2 = \sigma_{u^*}^2 = 0.02$. It shows the key result of our model: large unions reduce optimal exchange rate flexibility. The vertical axis on the right-hand side of Figure 2 corresponds to the case of Duarte and Obstfeld (2008)($n \to \infty$). Starting from there and keeping γ constant, we can see that an increase in union size ($n \downarrow$) increases exchange rate volatility at first and reduces it afterward. In particular, for any $\gamma > 0$ we can find a level $\bar{n}_\gamma$ such that if $n < \bar{n}_\gamma$ optimal exchange rate volatility is increasing in the number of unions under incomplete exchange rate pass-through.[20] If $n > \bar{n}_\gamma$ optimal exchange rate volatility is decreasing in the number of unions.

This result stems from the tradeoff faced by the optimal policy between the need to discipline wage behavior (limiting exchange rate flexibility and so inflation) and the incentive to use the terms of trade to reallocate hours worked and consumption across countries (increasing exchange rate volatility and so improving the terms of trade). An improvement in the terms of trade decreases the relative price of imported goods, triggering a rise in domestic consumers' international purchasing power and a reduction in the disutility of

[20] More formally, for any n such that $\Psi < \frac{1-\sqrt{7-7\gamma+2\gamma^2}}{2\gamma-3}$ $\left(\Psi > \frac{1-\sqrt{7-7\gamma+2\gamma^2}}{2\gamma-3}\right)$, the volatility of the exchange rate is decreasing (increasing) in the union's size, $1/n$.

Figure 2: Exchange rate volatility $\mathtt{var}_{t-1}(\widehat{\varepsilon}_t^{LCP})$



labor as the burden of production is shifted abroad. Optimal monetary policy can achieve an improvement in the terms of trade by increasing exchange rate volatility; on the other hand, it can achieve wage discipline and lower inflation by limiting exchange rate changes.[21]

The importance of nontraded goods, captured by γ, determines the relevant range for optimal exchange rate volatility between zero and a maximum value. In Figure 2 this maximum value is the volatility associated with the isoquant tangent to the horizontal line through the specific value of γ.[22] The number of unions in the economy, n, pins down the optimal volatility for the economy within this range. When $n > \bar{n}_\gamma$, the wage markup is low and the term-of-trade externality dominates so that a reduction in n demands more exchange rate flexibility. Vice versa, when $n < \bar{n}_\gamma$ the need to discipline wage behavior dominates and a reduction in n requires limiting exchange rate volatility. The effect of non-atomistic unions on optimal exchange rate volatility is stronger in the presence of few large unions – this corresponds to the left-hand side of Figure 2, where the isovariance curves are steeper.

[21]This is in line with the empirical findings in Daniels, Nourzad, and VanHoose (2006) and Cavallari (2001).

[22]For a given γ, this is the optimal exchange rate volatility for $n = \bar{n}_\gamma$.

For the calibration used in Figure 2 and $\gamma = 0.4$, going from $n = 2$ to $n = 3$ sectoral unions requires an 80 percentage point increase in exchange rate volatility.

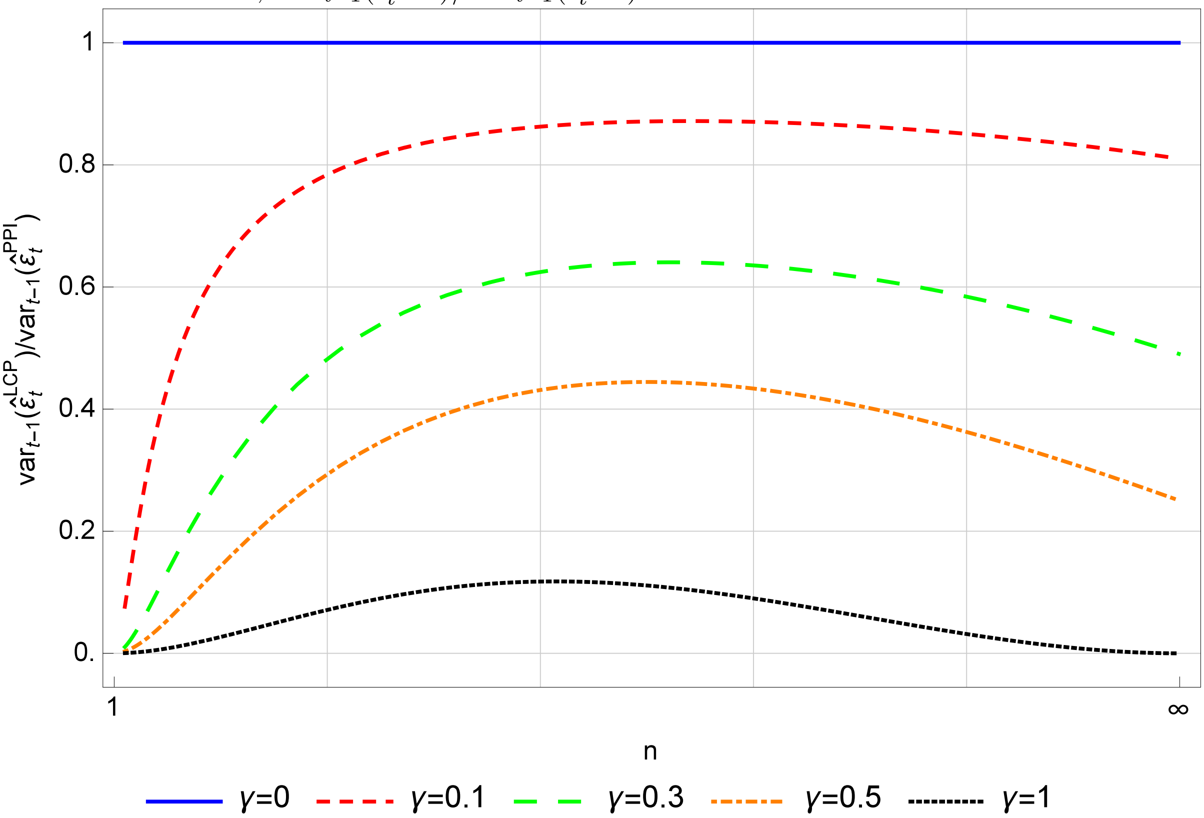
It is worth noticing that, in contrast with Devereux and Engel (2003) and Duarte and Obstfeld (2008), a fixed exchange rate is not necessarily optimal under LCP when Home and Foreign agents consume the same basket of goods. Figure 2 in fact shows that optimal exchange rate volatility is not zero for $\gamma = 1$. This stems from the fact that employment deviates from its flexible-price counterpart (see Appendix C) when unions are non-atomistic and optimal monetary policy faces a tradeoff between restraining exchange rate movements and allowing some exchange rate fluctuations in order to stabilize employment.

To further quantify the relevance of our channel, we compare the optimal exchange rate volatility predicted by our model with the volatility implied by an inward-looking policy. Drawing on De Paoli (2009) we plot the ratio of the optimal exchange rate volatility under LCP, $\mathtt{var}_{t-1}(\widehat{\varepsilon}_t^{LCP})$, to the exchange rate volatility under a policy of strict targeting of domestic price inflation, namely nontraded goods inflation, $\mathtt{var}_{t-1}(\widehat{\varepsilon}_t^{PPI})$. Figure 3 shows the ratio as function of $n > 1$ (horizontal axis) and for different values of γ. When $\gamma = 0$ and all goods are nontraded, the two policies coincide and the ratio is equal to one; as γ increases, the optimal policy requires more exchange rate targeting and the ratio falls below one. For any given value of γ, the ratio displays a hump-shaped pattern relative to n, which is consistent with the behavior of volatility documented in Figure 2. The hump-shaped pattern is asymmetric and the ratio is lower for low values of n relative to large ones, suggesting that the forces in favor of exchange rate stability become stronger in the presence of few large sectoral unions. Finally, non-atomistic unions can explain most of the discrepancy between the two policies when nontraded goods dominate the consumption bundle. When most goods are traded under LCP, the optimal policy requires exchange rate targeting and the additional incentive to reduce flexibility due to the presence of few large unions is relatively small. This is not the case when most goods are nontraded. Consider the case of $\gamma = 0.1$. The ratio is equal to 0.8 with atomistic unions ($n \to \infty$), but it approaches zero and n goes to one. This speaks to the quantitative importance of this mechanism.

5.2 Partial adjustment of prices and wages ($\tau, \nu \in (0, 1)$)

In this section we assess the effect of partial price and wage adjustments for the case of LCP. We realistically assume that $\nu < \tau$, namely the fraction of predetermined wages is larger than the fraction of predetermined prices. The results of the previous section carry through

Figure 3: Ratio of exchange rate volatility under optimal policy and under strict targeting of domestic inflation, $\mathtt{var}_{t-1}(\hat{\epsilon}_t^{LCP})/\mathtt{var}_{t-1}(\hat{\epsilon}_t^{PPI})$



this more general case: optimal exchange rate volatility displays a hump-shaped pattern relative to the number of unions.

Price rigidity. Partial price adjustment implies a fraction τ of firms with constant real marginal cost and revenue. Relative to the case of predetermined prices, unions anticipate a smaller impact of their wage claims on the equilibrium allocation. To the extent that wages and prices move instantaneously, productivity shocks (and exchange rate movements under LCP) do not shift the marginal cost (revenue) and the level of employment remains constant. As a result, wage responses are stronger. This implies that as τ goes up and more firms can adjust their prices, the cost in terms of consumption of inflationary wage hikes dominates. Hence, as τ goes up the optimal exchange rate volatility goes down.

Wage rigidity. As ν increases, wages are more flexible and the optimal policy has a stronger incentive to manipulate the terms of trade. Intuitively, unions anticipate that firms will not have an opportunity to adjust their prices in response to shocks and increase wages in response to a positive productive shock, which in turn reduces employment and increases workers' consumption. Optimal monetary policy may want to reinforce this mechanism with a larger depreciation if the wage markup is not too high, namely if union size is small. This implies that, for any given γ, the hump-shaped pattern of optimal exchange rate volatility relative to the number of unions shifts toward the left, thereby extending the range of n where the terms-of-trade externality dominates optimal monetary policy and exchange rate volatility is inversely related to n.

5.3 Monetary Policy Coordination

Are there gains from monetary coordination? Suppose monetary policies are chosen to maximize a weighted average of Home and Foreign expected utility:

$$\max_{\widehat{m}_t, \widehat{m}_t^*} E_{t-1}\left[\frac{1}{2}\mathcal{U}_t + \frac{1}{2}\mathcal{U}_t^*\right]. \tag{40}$$

Cooperative and non-cooperative optimal monetary policies are equal and therefore there are no gains from cooperation in three cases. The first case is with PCP when all wages are flexible ($\nu = 1$). As in Obstfeld and Rogoff (2002) and Corsetti and Pesenti (2005), optimal monetary policies are "inward looking" with price stickiness only. The nominal exchange rate fluctuates with relative productivity shocks, thereby moving the terms of trade and closing the domestic output gap. The other two cases arise under LCP. One is when unions are atomistic, wages are flexible and prices are fully predetermined ($n \to \infty,\ \nu = 1,\ \tau = 0$); the other is when wages are set by a single sectoral union (i.e. $n \to 1$) and wages are flexible. International spillovers typically arise because non-atomistic unions affect employment volatility by responding to exchange rate movements. In the two cases outlined above there are no spillovers between countries and monetary policies are strategically independent of each other.

5.4 Model-Data Comparison

Although the focus of our paper is normative, in this section we document the relationship between the optimal exchange-rate volatility under LCP predicted by our model, $\mathtt{var}_{t-1}(\hat{\epsilon}_t^{LCP})$, and the actual nominal exchange-rate volatility, σ_ε^2.

To calculate $\mathtt{var}_{t-1}(\hat{\epsilon}_t^{LCP})$, we need to calibrate six parameters: nominal price rigidity τ; nominal wage rigidity ν; the standard deviation of Home and Foreign labor productivity σ_u and σ_{u^*}; the share of traded goods γ; and the weight Ψ that unions attach to the response

Table 1: Calibration

Country (Code)	(1) τ	(2) ν	(3) σ_u	(4) σ_ε	(5) Ψ	(6) γ	(7) σ_{u^*}
Austria (AT)	0.248	0.070	0.023	0.043	0.654	0.208	0.022
Czech Republic (CZ)	0.223	0.116	0.039	0.107	0.661	0.326	0.041
Estonia (EE)	0.234	0.199	0.065	0.089	0.709	0.378	0.079
France (FR)	0.199	0.197	0.018	0.054	0.684	0.125	0.025
Greece (EL)	0.218	0.339	0.034	0.055	0.767	0.126	0.072
Hungary (HU)	0.171	0.026	0.047	0.118	0.688	0.238	0.032
Ireland (IE)	0.303	0.146	0.024	0.067	0.570	0.250	0.035
Italy (IT)	0.218	0.042	0.027	0.080	0.686	0.130	0.026
Lithuania (LT)	0.367	0.421	0.126	0.065	0.684	0.332	0.194
Netherlands (NL)	0.289	0.111	0.024	0.067	0.594	0.259	0.026
Portugal (PT)	0.201	0.059	0.035	0.031	0.727	0.156	0.036
Slovenia (SI)	0.249	0.272	0.025	0.062	0.669	0.355	0.040
Spain (ES)	0.181	0.119	0.030	0.045	0.654	0.107	0.039
United States (US)	0.627	0.289	0.012	0.093	0.827	0.066	0.051

to monetary innovations. We assume that a period in the model is one year.

Nominal price and wage rigidity. We use data from the Wage Dynamics Network (WDN) survey on wage and pricing policies at the firm level. The WDN survey was carried out by 17 national central banks between the end of 2007 and the first half of 2008. It provides a unique cross-country, harmonized dataset that simultaneously measures price and wage stickiness. We use data for the following thirteen European countries: Austria, Czech Republic, Estonia, France, Greece, Hungary, Ireland, Italy, Lithuania, Netherlands, Portugal, Slovenia, Spain. All countries in the sample, except the Czech Republic and Hungary, belong to the Euro Zone. To benchmark and compare our results, we have collected data also for the United States. Columns 1 and 2 of Table 1 report, respectively, the frequency of price and wage changes. For European countries τ is the fraction of firms that adjusts the price of their main product more than once a year; ν is the fraction of firms changing the wage for their main occupational group more than once a year. We focus on employment-adjusted-weighted data. For the United States we build on the micro evidence for price and wage setting respectively drawn from Weber (2015) and Barattieri, Basu, and Gottschalk (2014). See Appendix D for additional information on calculation of τ and ν.

Standard deviation of labor productivity and the nominal exchange rate. We use annual observations from Feenstra, Inklaar, and Timmer (2015), also known as the Penn

World Tables, Release 8.1. For labor productivity, we take the log of output-side PPP-adjusted real GDP per worker and then apply the Hodrick-Prescott filter. Since the WDN survey was conducted between 2007 and 2008, we covers a sample period 1950-2009 and 1970-2009 for Czech Republic, Estonia, Hungary, Lithuania and Slovenia. We calibrate the standard deviation of foreign productivity (σ_{u^*}) so that labor volatility in the calibrated model matches the standard deviation of HP residuals of log employment in the data. This target is arbitrarily chosen to emphasize that we consider this model mostly illustrative and not able to generate realistic predictions for the overall level of volatility in the economy.
For the nominal exchange rate, we use data from BIS on nominal effective exchange rate indices from 1994:1 to 2009:12. We then calculate the standard deviation of the HP residuals for domestic productivity and the nominal exchange rate. See Appendix D for further details. The standard deviation of real GDP per worker and the standard deviation of foreign productivity are respectively reported in column 3 and 7 of Table 1. The standard deviation of the nominal exchange rate is reported in column 4.

Labor market concentration and openness. In our model $1/n$ captures the degree of centralization in wage setting. We have no data on σ, the elasticity of substitution across labor types, for a large set of countries. Since there is a monotonic relationship between Ψ and n (see footnote 16), we approximate Ψ with $1 - \sqrt{Haff}$, where $Haff$ denotes the mean value of the sectorial Herfindal index of union concentration – see Appendix D for data sources. Ψ values for each country are reported in column 5 of Table 1
We measure γ as the degree of openness. Following Duarte, Restuccia, and Waddle (2007), we construct openness as $\gamma = \frac{exp+imp}{2(gdp+imp)}$, where exp denotes exports of goods and services at constant national 2005 prices, imp are imports of goods and services at constant national 2005 prices, and gdp indicates GDP at constant national 2005 prices. The measure of openness ranges between zero and one and it is reported in column 6 of Table 1.

Using the parameters specified in Table 1 we calculate the optimal exchange-rate volatility predicted by our model, ($\mathtt{var}_{t-1}(\hat{\epsilon}_t^{LCP})$). Figure 4 reports the the optimal exchange-rate volatility on the vertical axis and the observed one on the horizontal axis in the sample period 1994-2009 for each country. The discrepancy between optimal and observed volatility of exchange rate is arguably small for most countries in our sample except Lithuania, Portugal, Spain and Greece. In particular, the optimal volatility of exchange rate for these countries is higher than the exchange-rate volatility in the data.

Regarding Lithuania, the model predicts that the optimal volatility should be 2.8 times as much as the volatility in the data. Lithuania pegged the litas to the US dollar under a

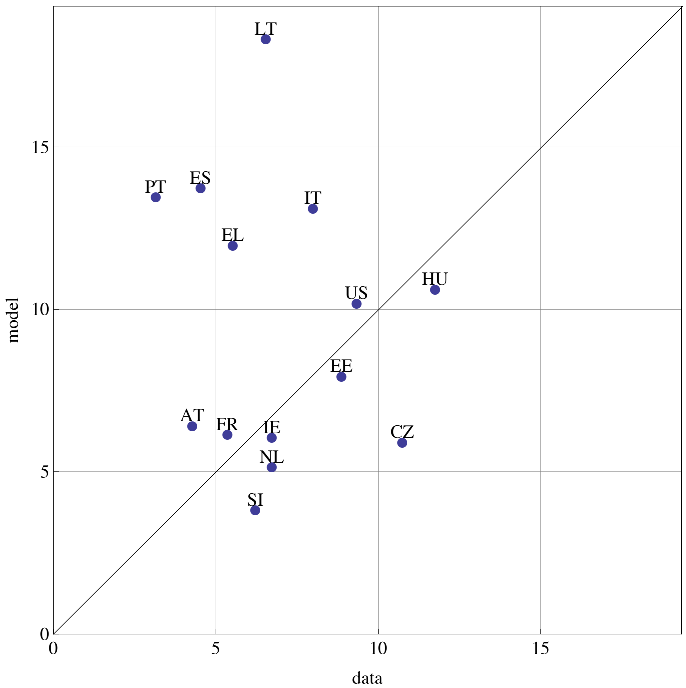


Figure 4: Model-data comparison (1994-2009): exchange-rate standard deviation (%).

currency board arrangement from 1994 to 2002. From 2002 to 2014 the litas was pegged to the euro. However, its labor market is the most flexible in our sample. According to our model this implies that the central bank has a greater incentive to manipulate the exchange rate and so the terms of trade via wage adjustments.

In the sample period Greece, Portugal and Spain display optimal volatilities of exchange rate which are respectively 2.2, 4.3, and 3.0 times as much as the ones in the data. Greece has a degree of openness and an effective exchange-rate volatility equal to France in the data; however, concentration in the labor market and nominal wage rigidities in the French private sector are higher than in Greece. These two features call for more volatility in the optimal exchange rate in the Hellenic Republic, since the incentive for monetary policy to move the terms of trade are larger. By the same token, Portugal and Austria mainly differ in labor union concentration at industry level. In particular labor markets are more concentrated in Austria than in Portugal. This accounts for more exchange-rate volatility in the latter. Finally, Spain and Netherlands have a similar calibration except for two country-specific factors: price flexibility and openness are higher in Netherlands. This renders a reduction in exchange-rate volatility relatively more efficient in the continental country.

In Figure 5 we explicitly consider the effects of the introduction of the euro. The question

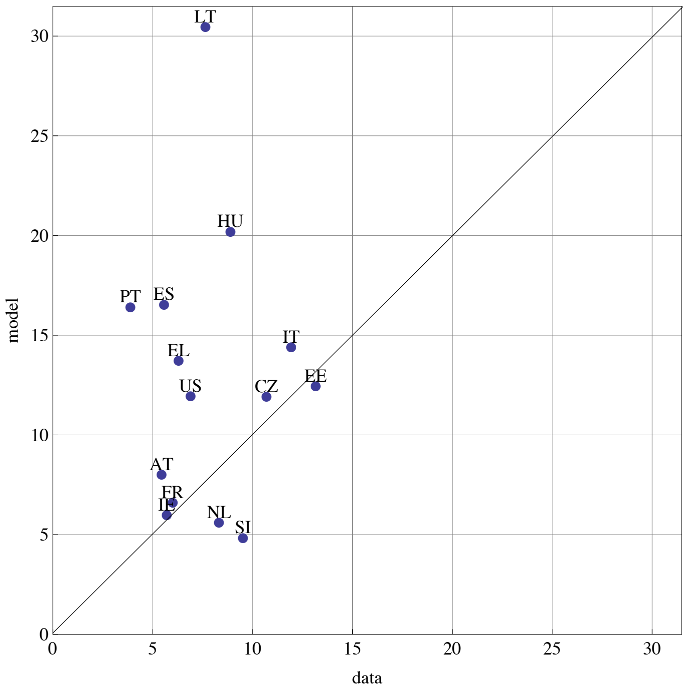


Figure 5: Model-data comparison (1994-1998): exchange-rate standard deviation (%).

arises whether optimal and effective exchange-rate dynamics differ after the introduction of the euro in comparison with the period before the start of the European Monetary Union (EMU). Split sample analysis for the pre-1999 period reveals a limited impact on the previous results except for Hungary. This country in the pre-99 period was relatively a closer economy than in the post-99 period. The degree of openness moved from 0.16 to 0.41, thereby calling for less exchange-rate volatility.

6 Concluding remarks

We develop a tractable, stochastic model in line with the NOEM approach with nontraded goods, incomplete exchange rate pass-through and sectoral non-atomistic unions. In this environment we characterize optimal monetary policy and its consequences for exchange rate volatility. Our main finding is that, under LCP, sufficient concentration in the labor market reduces optimal exchange rate volatility even in the presence of nontraded goods. With pricing-to-market exchange rate flexibility does not align consumer prices across borders but rather leads to more volatile firm profits and higher prices and wages when unions are large. By committing to reduce exchange rate fluctuations optimal monetary policy can also reduce inflationary wage demands.

Our findings have policy implications. Commitment of monetary policy goes an extra step in models with large players - large unions in our case - because these players take into account the monetary policy response to their actions. In particular, risk leads to suboptimal wage setting in our setting. By limiting exchange rate volatility optimal monetary policy can reduce risk and moderate unit labor costs. We believe this is one mechanism, possibly among others, at the heart of the desire for a stable currency in open economies. Our result suggests that an explicit commitment to moderate exchange rate fluctuations is beneficial.

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Appendix

A Impact of union's wage on aggregate wage

From the wage index (13), we obtain

$$\begin{aligned}
\frac{\partial W_t}{\partial W_t(x)} &= \frac{\partial}{\partial W_t(x)} \left[\int_0^1 W_t(z)^{1-\sigma} \mathrm{d}z \right]^{\frac{1}{1-\sigma}} \\
&= \frac{\partial}{\partial W_t(x)} \left[\int_{z \in x} W_t(z)^{1-\sigma} \mathrm{d}z + \int_{z \notin x} W_t(z)^{1-\sigma} \mathrm{d}z \right]^{\frac{1}{1-\sigma}} \\
&= \frac{1}{n} \left[\frac{W_t(x)}{W_t} \right]^{-\sigma} = \frac{1}{n} \qquad \text{(A.1)}
\end{aligned}$$

where the last equality holds in a symmetric equilibrium, i.e. when $W(x) = W$.

B Derivation of the optimal wage setting

From eq. (4) and (5) the exchange rate can be expressed as

$$\mathcal{E}_t = \frac{M_t}{M_t^*}. \qquad \text{(B.1)}$$

For a given level of foreign monetary policy stance, an expansionary monetary policy shock (higher M_t and higher nominal expenditure $P_t C_t$ in equilibrium) is associated with a depreciation of the exchange rate.

From the aggregate goods market clearing conditions we obtain the following aggregate labor demands:

$$L_{Ht} = \frac{\gamma}{2A_t} \left(\frac{P_t C_t}{P_{Ht}} + \frac{P_t^* C_t^*}{P_{Ht}^*} \right) = \frac{\gamma}{2A_t} \frac{M_t}{P_{Ht}} \left(1 + \frac{P_{Ht}}{\mathcal{E}_t P_{Ht}^*} \right) \qquad \text{(B.2)}$$

$$L_{Nt} = \frac{1-\gamma}{A_t}\frac{P_t C_t}{P_{Nt}} = \frac{1-\gamma}{A_t}\frac{M_t}{P_{Nt}}, \tag{B.3}$$

where we used (B.1).

Without nominal rigidities, the law of one price holds ($\mathcal{E}_t P^*_{Ht} = P_{Ht}$) and employment is given by

$$L^{flex}_{Ht} = \frac{\gamma}{\mathcal{M}_p}\frac{M_t}{W_{Ht}} \qquad\qquad L^{flex}_{Nt} = \frac{1-\gamma}{\mathcal{M}_p}\frac{M_t}{W_{Nt}}. \tag{B.4}$$

The elasticity of aggregate labor demand to wage is

$$-\frac{\partial \log L^{flex}_{jt}}{\partial \log W_{jt}} = 1, \qquad j \in \{H, N\}. \tag{B.5}$$

The elasticity of aggregate labor demand for labor type z (14) to wage with flexible prices is

$$-\frac{\partial \log L^{flex}_{jt}(x)}{\partial \log W_{jt}(x)} = \sigma\left(1 - \frac{1}{n}\right) + \frac{1}{n} \qquad j \in \{H, N\}, \tag{B.6}$$

where we used (A.1) taking monetary stance as given.

Now, each union maximizes

$$V_{jt}(x) = n\int_{z\in x}\left[\frac{1}{M_t}W_{jt}(x)L_{jt}(z) - kL_{jt}(z)\right]\mathrm{d}z \qquad j \in \{H, N\}, \tag{B.7}$$

with respect to $W_{jt}(x)$ subject to the labor demand (14), the budget constraint (3) and the optimal price setting (15).

The first-order condition for unions operating in the non-traded goods sector is

$$\begin{aligned} 0 \;=\; & (1-\sigma)\frac{L_{Nt}(i)}{M_t} + \frac{\sigma}{n}\frac{W_{Nt}(i)}{W_{Nt}}\frac{L_{Nt}(i)}{M_t} - \frac{\tau}{n}\frac{W_{Nt}(i)L_{Nt}(i)}{M_t W_{Nt}} + \frac{\tau-1}{nA_t}\frac{W_{Nt}(i)L_{Nt}(i)}{M_t \mathrm{E}_{t-1}\frac{W_{Nt}}{A_t}} + \\ & +\sigma k\frac{L_{Nt}(i)}{W_{Nt}(i)} + \frac{\tau}{n}k\frac{L_{Nt}(i)}{W_{Nt}} - \frac{\tau-1}{nA_t}k\frac{L_{Nt}(i)}{\mathrm{E}_{t-1}\frac{W_{Nt}}{A_t}} - \sigma k\frac{L_{Nt}(i)}{nW_{Nt}}. \end{aligned} \tag{B.8}$$

In a symmetric equilibrium, $W_{Nt}(i) = W_{Nt}$, the above expression boils down to

$$\begin{aligned} 0 \;=\; & \frac{L_{Nt}}{M_t}\left[1 - \sigma + \frac{\sigma}{n} - \frac{\tau}{n} + \frac{\tau-1}{nA_t}\frac{W_{Nt}}{\mathrm{E}_{t-1}\frac{W_{Nt}}{A_t}}\right] + \\ & +k\frac{L_{Nt}}{M_t}\left[\sigma\frac{M_t}{W_{Nt}} + \frac{\tau}{n}\frac{M_t}{W_{Nt}} - \frac{\tau-1}{nA_t}\frac{M_t}{\mathrm{E}_{t-1}\frac{W_{Nt}}{A_t}} - \sigma\frac{M_t}{nW_{Nt}}\right]. \end{aligned} \tag{B.9}$$

Thus, the steady state level of the first-order condition is given by

$$\frac{W_N}{M} = k\left[1+\frac{n}{(n-1)(\sigma-1)}\right] = k\mathcal{M}_w. \tag{B.10}$$

Log-linearizing (B.9) around the symmetric steady state (B.10) yields eq. (31) in the text.

Under PCP, the first-order condition for unions operating in the tradables is

$$\begin{aligned} 0 \quad = \quad & 2\frac{W_{Ht}L_{Ht}}{M_t}\left[\frac{1-\sigma}{W_{Ht}}\left(1-\frac{1}{n}\right)+\frac{1-\tau}{nW_{Ht}}+\frac{\tau-1}{nA_t}\frac{1}{\mathrm{E}_{t-1}\frac{W_{Ht}}{A_t}}\right]+ \\ & +2kL_{Ht}\left[\frac{\sigma}{W_{Ht}}\left(1-\frac{1}{n}\right)+\frac{\tau}{nW_{Ht}}-\frac{\tau-1}{nA_t}\frac{1}{\mathrm{E}_{t-1}\frac{W_{Ht}}{A_t}}\right]. \end{aligned} \tag{B.11}$$

Under LCP, the first-order condition for unions operating in the tradables is

$$\begin{aligned} 0 \quad = \quad & \frac{W_{Ht}L_{Ht}}{M_t}\left[2\frac{1-\sigma}{W_{Ht}}\left(1-\frac{1}{n}\right)+2\frac{1-\tau}{nW_{Ht}}+\frac{\tau-1}{nA_t}\frac{1}{\mathrm{E}_{t-1}\frac{W_{Ht}}{A_t}}+\frac{\tau-1}{nA_t}\frac{\mathcal{E}_t^{-1}}{\mathrm{E}_{t-1}\frac{W_{Ht}\mathcal{E}_t^{-1}}{A_t}}\right]+ \\ & +kL_{Ht}\left[2\frac{\sigma}{W_{Ht}}\left(1-\frac{1}{n}\right)+2\frac{\tau}{nW_{Ht}}-\frac{\tau-1}{nA_t}\frac{1}{\mathrm{E}_{t-1}\frac{W_{Ht}}{A_t}}-\frac{\tau-1}{nA_t}\frac{\mathcal{E}_t^{-1}}{\mathrm{E}_{t-1}\frac{W_{Ht}\mathcal{E}_t^{-1}}{A_t}}\right]. \end{aligned} \tag{B.12}$$

Notice that the steady state of (B.11) and (B.12) is equal to (B.10). Log-linearizing (B.11) and (B.12) around that steady state yields (32) in the text.

C Derivation of expected utility

In order to derive the expected utility function that the monetary authority seeks to maximize, we start from expected consumption:

$$\begin{aligned} \mathrm{E}_{t-1}\log\frac{C_t^{flex}}{C_t^j} \quad & = \quad \mathrm{E}_{t-1}\log\left(\frac{C_t^{flex}}{\bar{C}_t^j}\right)^{1-\tau} = (1-\tau)\mathrm{E}_{t-1}\left\{\log\frac{M_t}{P_t^{flex}}-\log\frac{M_t}{\bar{P}_t^j}\right\} = \\ & = \quad (1-\tau)\mathrm{E}_{t-1}\left\{\bar{p}_t^j-p_t^{flex}\right\} \qquad j\in\{PCP, LCP\}, \end{aligned} \tag{C.1}$$

where

$$\begin{aligned}
\mathrm{E}_{t-1}\log\frac{\bar{P}_t^{LCP}}{P_t^{flex}} &= \mathrm{E}_{t-1}\log\frac{\left[\mathrm{E}_{t-1}\frac{W_{Ht}}{A_t}\right]^{\frac{\gamma}{2}}\left[\mathrm{E}_{t-1}\frac{\mathcal{E}_t W^*_{Ft}}{A^*_t}\right]^{\frac{\gamma}{2}}\left[\mathrm{E}_{t-1}\frac{W_{Nt}}{A_t}\right]^{1-\gamma}}{\left[\frac{W_{Ht}}{A_t}\right]^{\frac{\gamma}{2}}\left[\frac{\mathcal{E}_t W^*_{Ft}}{A^*_t}\right]^{\frac{\gamma}{2}}\left[\frac{W_{Nt}}{A_t}\right]^{1-\gamma}} \\
&= \frac{\gamma}{2}\left[\frac{\sigma^2_{w_H}}{2}+\frac{\sigma^2_u}{2}-\sigma_{w_H u}-\sigma_{w^*_F u^*}+\sigma_{w^*_F\varepsilon}-\sigma_{\varepsilon u^*}+\frac{\sigma^2_{w^*_F}}{2}+\frac{\sigma^2_{u^*}}{2}+\frac{\sigma^2_\varepsilon}{2}\right] \\
&\quad +(1-\gamma)\left[\frac{\sigma^2_{w_N}}{2}+\frac{\sigma^2_u}{2}-\sigma_{w_N u}\right] \\
&= \frac{\gamma}{2}\left[\frac{\mathrm{E}_{t-1}(\widehat{w}_{Ht}-\widehat{a}_t)^2}{2}+\frac{\mathrm{E}_{t-1}(\widehat{w}^*_{Ft}-\widehat{a}^*_t+\widehat{\varepsilon}_t)^2}{2}\right]+(1-\gamma)\frac{\mathrm{E}_{t-1}(\widehat{w}_{Nt}-\widehat{a}_t)^2}{2}
\end{aligned} \tag{C.2}$$

and

$$\begin{aligned}
\mathrm{E}_{t-1}\log\frac{\bar{P}_t^{PCP}}{P_t^{flex}} &= \mathrm{E}_{t-1}\log\frac{\left[\mathrm{E}_{t-1}\frac{W_{Ht}}{A_t}\right]^{\frac{\gamma}{2}}\left[\mathcal{E}_t\mathrm{E}_{t-1}\frac{W^*_{Ft}}{A^*_t}\right]^{\frac{\gamma}{2}}\left[\mathrm{E}_{t-1}\frac{W_{Nt}}{A_t}\right]^{1-\gamma}}{\left[\frac{W_{Ht}}{A_t}\right]^{\frac{\gamma}{2}}\left[\frac{\mathcal{E}_t W^*_{Ft}}{A^*_t}\right]^{\frac{\gamma}{2}}\left[\frac{W_{Nt}}{A_t}\right]^{1-\gamma}} \\
&= \frac{\gamma}{2}\left[\frac{\sigma^2_{w_H}}{2}+\frac{\sigma^2_u}{2}-\sigma_{w_H u}-\sigma_{w^*_F u^*}+\frac{\sigma^2_{w^*_F}}{2}+\frac{\sigma^2_{u^*}}{2}\right]+(1-\gamma)\left[\frac{\sigma^2_{w_N}}{2}+\frac{\sigma^2_u}{2}-\sigma_{w_N u}\right] \\
&= \frac{\gamma}{2}\left[\frac{\mathrm{E}_{t-1}(\widehat{w}_{Ht}-\widehat{a}_t)^2}{2}+\frac{\mathrm{E}_{t-1}(\widehat{w}^*_{Ft}-\widehat{a}^*_t)^2}{2}\right]+(1-\gamma)\frac{\mathrm{E}_{t-1}(\widehat{w}_{Nt}-\widehat{a}_t)^2}{2}.
\end{aligned} \tag{C.3}$$

We now turn to expected employment. In order to be able to arrive at a closed-form solution without having to resort to numerical simulation, we will approximate the exponential terms in the welfare functions by linear expressions. For example, $\exp(\widehat{x}_t)$ is approximated by $1+\widehat{x}_t$. Using (B.2) and (B.4) we obtain

$$
\begin{aligned}
\mathrm{E}_{t-1}\left\{L_{Ht}^{flex}-L_{Ht}^{LCP}\right\} &= \frac{\gamma}{\mathcal{M}_p}\mathrm{E}_{t-1}\left\{\frac{M_t}{W_{Ht}}-\frac{M_t}{2A_t}\left(\frac{W_{Ht}}{A_t}\right)^{-\tau}\left[\left(\mathrm{E}_{t-1}\frac{W_{Ht}}{A_t}\right)^{\tau-1}\right.\right.\\
&\quad \left.\left.+\mathcal{E}_t^{\tau-1}\left(\mathrm{E}_{t-1}\frac{W_{Ht}}{A_t\mathcal{E}_t}\right)^{\tau-1}\right]\right\}\\
&= \frac{\gamma}{k\mathcal{M}_p}(1-\tau)\left\{\sigma_{w_H}^2+\frac{\sigma_{\varepsilon m}-\sigma_{\varepsilon w_H}}{2}+\sigma_{mu}-\sigma_{mw_H}-\sigma_{w_H u}\right.\\
&\quad \left.+\frac{\tau}{2}\left[\frac{\sigma_\varepsilon^2}{2}+\sigma_u^2+\sigma_{w_H}^2+\sigma_{\varepsilon u}-\sigma_{\varepsilon w_H}-2\sigma_{w_H u}\right]\right\}\\
&= \frac{\gamma}{k\mathcal{M}_p}(1-\tau)\mathrm{E}_{t-1}\left\{(\widehat{w}_{Ht}-\widehat{m}_t)(\widehat{w}_{Ht}-\frac{\widehat{\varepsilon}_t}{2}-\widehat{a}_t)\right.\\
&\quad \left.+\frac{\tau}{2}\left[(\widehat{w}_{Ht}-\frac{\widehat{\varepsilon}_t}{2}-\widehat{a}_t)^2+\left(\frac{\widehat{\varepsilon}_t}{2}\right)^2\right]\right\},
\end{aligned}
\tag{C.4}
$$

$$
\begin{aligned}
\mathrm{E}_{t-1}\left\{L_{Ht}^{flex}-L_{Ht}^{PCP}\right\} &= \frac{\gamma}{\mathcal{M}_p}\mathrm{E}_{t-1}\left\{\frac{M_t}{W_{Ht}}-\frac{M_t}{A_t}\left[\left(\mathrm{E}_{t-1}\frac{W_{Ht}}{A_t}\right)^{\tau-1}\left(\frac{W_{Ht}}{A_t}\right)^{-\tau}\right]\right\}\\
&= \frac{\gamma}{k\mathcal{M}_p}(1-\tau)\left\{\sigma_{w_H}^2+\sigma_{mu}-\sigma_{mw_H}-\sigma_{w_H u}+\frac{\tau}{2}\left[\sigma_u^2+\sigma_{w_H}^2-2\sigma_{w_H u}\right]\right\}\\
&= \frac{\gamma}{k\mathcal{M}_p}(1-\tau)\mathrm{E}_{t-1}\left\{(\widehat{w}_{Ht}-\widehat{m}_t)(\widehat{w}_{Ht}-\widehat{a}_t)+\frac{\tau}{2}(\widehat{w}_{Ht}-\widehat{a}_t)^2\right\}.
\end{aligned}
\tag{C.5}
$$

Similarly, from (B.3) and (B.4) we can write the following expression:

$$
\begin{aligned}
\mathrm{E}_{t-1}\left\{L_{Nt}^{flex}-L_{Nt}\right\} &= \frac{1-\gamma}{\mathcal{M}_p}\mathrm{E}_{t-1}\left\{\frac{M_t}{W_{Nt}}-\frac{M_t}{A_t}\left[\left(\mathrm{E}_{t-1}\frac{W_{Nt}}{A_t}\right)^{\tau-1}\left(\frac{W_{Nt}}{A_t}\right)^{-\tau}\right]\right\}\\
&= \frac{1-\gamma}{k\mathcal{M}_p}(1-\tau)\left\{\sigma_{w_N}^2+\sigma_{mu}-\sigma_{mw_N}-\sigma_{w_N u}+\frac{\tau}{2}\left[\sigma_u^2+\sigma_{w_N}^2-2\sigma_{w_N u}\right]\right\}\\
&= \frac{1-\gamma}{k\mathcal{M}_p}(1-\tau)\mathrm{E}_{t-1}\left\{(\widehat{w}_{Nt}-\widehat{m}_t)(\widehat{w}_{Nt}-\widehat{a}_t)+\frac{\tau}{2}(\widehat{w}_{Nt}-\widehat{a}_t)^2\right\}.
\end{aligned}
\tag{C.6}
$$

Thus, the expected utility under LCP and PCP is given respectively by

$$
\mathrm{E}_{t-1}\left\{U_t^{flex}-U_t^{LCP}\right\} = (1-\tau)(\mathrm{C}.2)-k(\mathrm{C}.4)-k(\mathrm{C}.6) \tag{C.7}
$$

and

$$\mathrm{E}_{t-1}\left\{U_t^{flex} - U_t^{PCP}\right\} = (1-\tau)(\mathrm{C}.3) - k(\mathrm{C}.5) - k(\mathrm{C}.6). \quad (\mathrm{C}.8)$$

Expressions (35) in the text are derived by maximizing the above expected utilities with respect to $\widehat{m}_t$, subject to the optimal wage decisions (31) and (32) and setting $\tau = 0$ and $\nu = 1$.

D Data

Price and Wage Stickiness

For European countries we use Wage Dynamics Network Data from the European Central Bank. Data on price changes are taken from Question 31: "Under normal circumstances, how often is the price of the firm's main product typically changed?". τ in Table 1 corresponds to the frequency of firms that change their price *more than once a year*. Data on wage changes are collected from Question 9: "How frequently is the base wage of an employee belonging to the main occupational group in your firm typically changed in your firm?" We set ν in Table 1 equal to the highest frequency of firm-level wage change among the type *more than once a year* whose determinants are unrelated to tenure and/or inflation or due to tenure or due to inflation. We adopt employment-adjusted weights, where the weight attached to each firm in the sample refers to how many employees that observation represents in the population. For the United States we build on the micro evidence for price and wage setting, respectively drawn from Weber (2015) and Barattieri, Basu, and Gottschalk (2014). Barattieri, Basu, and Gottschalk (2014) estimate an average quarterly probability of a nominal wage change between 21.1 and 26.6 percent. As for Wage Dynamics Network data, we choose the highest frequency. Weber (2015) estimates that prices are expected to remain unchanged for 2.17 quarters. From expected lifetime of prices we can infer the Calvo parameter, namely price remains unchanged with probability equals to 0.54 each quarter. Now, in order to calculate the probability of changing prices/wages *more than once a year*, we apply the following formula $\sum_{t=2}^{4}\binom{4}{t}x^t\,(1-x)^{4-t}$, where x is equal to 46.1 and 26.6 percent for getting respectively τ and ν in Table 1.

Labor Productivity

We use data from the Penn World Tables, Release 8.1. The standard deviation of labor productivity σ_u is calculated as follows: a) we calculate PPP-adjusted real GDP per worker as *rgdpo/emp*; b) we take log and then apply the Hodrick-Prescott filter with smoothing parameter equal to 100; c) we calculate the standard deviation of HP residuals. The standard deviation σ_{u^*} is pinned down so that volatility of employment in the calibrated model matches volatility of employment calculated as the standard deviation of HP residuals of the log of *emp*.

Nominal Exchange Rate

We use monthly BIS nominal, broad effective exchange rate indices for the 1994:1-2009:12 period. The standard deviation of nominal effective exchange rate is calculated as follows: a) we take log and then apply the Hodrick-Prescott filter with smoothing parameter equal to 14400; b) we calculate the standard deviation of HP residuals; c) we multiply monthly standard deviation of HP residuals by $\sqrt{12}$ so as to obtain annualized standard deviations.

Labor Market Concentration

We use data from the ICTWSS Database on Institutional Characteristics of Trade Unions, Wage Setting, State Intervention and Social Pacts. We set Ψ equal to $1 - \sqrt{Haff}$, the Herfindahl index at sectoral level of union membership concentration. The variable $Haff$ takes values between 0 and 1. We take the average value of $Haff$ over the entire sample period for each country.

Openness

Data are collected from the Penn World Tables, Release 8.1. Openness is measured as $\frac{exp+imp}{2(gdp+imp)}$, where exp denotes exports of goods and services, imp are imports of goods and services, and gdp indicates GDP. All variables are measured at constant national 2005 prices. We take the average value over the entire sample period for each country. This measure of openness ranges between zero and one: zero when both export and imports are zero; one as output and domestic spending approach zero and the value of exports equals the value of imports.