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Monopolistic Unions, Brainard Uncertainty, and Optimal Monetary Policy

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Abstract

Some authors have argued that multiplicative uncertainty may benefit society as the cautionary motive reduces the inflation bias. However, when there are non-atomistic wage setters, higher multiplicative uncertainty may raise the wage premium and unemployment and thus reduce welfare. Furthermore, since central bank preferences also affect the wage premium, delegating policy to an independent central banker with an optimal degree of conservatism cannot, in general, deliver a second-best outcome.

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1 Introduction

In a landmark article Brainard (1967) showed that when policy processes are characterized by multiplicative uncertainty, optimal policy typically ought to be more cautious than the certainty-equivalent policy. Some authors, i.e. Pearce and Sobue (1997), Schellekens (2002), Swank (1994) and others, have argued that Brainard uncertainty[1] may be welfare-enhancing since policy caution is shown to reduce the inflation bias resulting from a standard time inconsistency problem à la Kydland and Prescott (1977) and Barro and Gordon (1983).

Going one step further, Schellekens suggests that, in the presence of Brainard uncertainty, a more careful specification of central bank preferences allows a distinction between two notions of conservatism termed 'stability-conservatism' and 'target-conservatism.' Whereas delegation of monetary policy to a weight-conservative central banker as in Rogoff (1985) only delivers a third-best outcome, stability-conservatism and target-conservatism can, in principle, deliver a second-best outcome.

In a largely unrelated branch of the literature, numerous authors have recently challenged the conventional wisdom that monetary institutions only affect inflation and not the real economy.[2] They show that when the labor market is populated by non-atomistic wage setters with market power, institutional characteristics do affect real variables.

In this paper, it is argued that Brainard uncertainty is interpretable as an institutional feature which affects real variables. In particular, higher Brainard uncertainty typically raises the real wage premium and unemployment and the variances of inflation and unemployment, contradicting the claims by Schellekens and others. Furthermore, Schellekens' argument that a more refined notion of conservatism is able to restore the best feasible equilibrium breaks down with non-atomistic wage setters.

2 Model Setup

2.1 The Labor Market

The following is an adaptation of Cukierman and Lippi (1999) (henceforth CL) who model an economy consisting of n identical independent inflation-averse monopolistic unions, each facing the loss function

$$\Omega_j = E\left\{-2w_j + \chi u_j^2 + \xi\pi^2\right\}; \qquad \chi, \xi > 0; \tag{1}$$

where w_j is the (logarithm of the) real wage received by the union j's members, u_j is the unemployment rate among members of union j, $\pi = p - p_{-1}$ is the rate of inflation

[1] The terms Brainard uncertainty, parameter uncertainty and multiplicative uncertainty are used interchangeably.

[2] These include, but are not limited to, Akhand (1992), Cubitt (1992), Cukierman and Lippi (1999, 2005), Guzzo and Velasco (1999), Lawler (2000, 2002), Lippi (2003), Skott (1997), and Soskice and Iversen (2000).

where p is the log of the price level, and E is the standard expectations operator conditional on previous period's information.[3] Labor is imperfectly substitutable across unions and supplied inelastically. All workers are unionized and evenly distributed across the n unions. The demand for labor facing union j is given by

$$L_j^d = \left[\frac{\alpha}{n}(d - w_j) - \gamma(w_j - \overline{w})\right] L; \qquad \alpha, \gamma, > 0; \qquad d > 1/\alpha; \tag{2}$$

where L denotes total labor supply in the economy and $\overline{w} = \sum_{j=1}^{n} w_j/n$ is the economy-wide mean of w_j across all unions. Such a labor demand function can be derived from a firm's standard profit maximization problem where the production function is characterized by increasing or decreasing returns to scale.

As in CL, aggregate demand for labor is

$$L^d = \sum_{j=1}^{n} L_j^d = \alpha(d - \overline{w}) L. \tag{3}$$

The economy-wide unemployment rate, absent any shocks, is defined as

$$\widehat{u} \equiv \frac{L - L^d}{L} = \alpha\left(\overline{W} - \pi - p_{-1} - w^c\right) \tag{4}$$

where $\overline{W}$ is the economy-wide mean of the (log) nominal wage and $w^c \equiv d - 1/\alpha$ is the (theoretical) market clearing wage that would generate an unemployment rate of zero. Actual unemployment is given by

$$u = \widehat{u} + \varepsilon = \alpha\left(\overline{W} - \pi - p_{-1} - w^c\right) + \varepsilon \tag{5}$$

where ε is a macro-shock with mean zero and variance σ_ε^2 which the central bank observes but unions do not.

2.2 The Central Bank

The modelling of the central bank's problem closely follows Schellekens (2002). The central bank minimizes the following generalized quadratic loss function:[4]

$$\begin{aligned} L &= \mu_1 \{E[\pi]\}^2 + \theta_1 Var[\pi] \\ &\quad + \mu_2 \{E[u]\}^2 + \theta_2 Var[u]. \end{aligned} \tag{6}$$

[3] For thorough discussions of trade union preferences see Cahuc and Zylberberg (2004), Cukierman and Lippi (1999), Layard et al. (1991), and Oswald (1982). For a justification of including the inflation term in the unions' loss function see Skott (1997).

[4] The standard quadratic loss function is merely a special case with $\mu_1 = \theta_1 = I$, some positive number, and $\mu_2 = \theta_2 = 1$. The benefit of using the generalized quadratic loss function will become apparent later.

Inflation is given by

$$\pi = si \tag{7}$$

where s, the control error, is an iid random variable with positive support, a mean of unity, and finite variance σ_s^2, and i represents the deviation of the central bank's monetary policy instrument from its neutral level, viz. that level which, absent any shocks, keeps the inflation rate constant at zero. Note that while only the central bank observes ε, neither it nor the unions observe s.

The quadratic nature of the loss function implies that the central bank's optimal policy rule will take the linear form

$$i = \Lambda_1 + \Lambda_2 \varepsilon, \tag{8}$$

where Λ_1 and Λ_2, yet to be determined, represent the central bank's control variables.

3 Equilibrium

In this game unions play Nash with each other but collectively act as Stackelberg leader vis-à-vis the central bank. Hence, the timing of events is as follows: First, unions set nominal wages. Second, the supply shock is realized, after which the central bank chooses monetary policy. Finally, the control error is realized and the unions and the central bank receive their respective payoffs.

3.1 Solution to Central Bank's Problem

The model is solved by backward induction. The central bank's problem is to minimize (6) subject to (5), taking $\overline{W}$ as given. The optimal solution for Λ_1 is given by

$$\Lambda_1 = \frac{\mu_2 \alpha^2}{\mu_1 + \mu_2 \alpha^2 + \sigma_s^2 (\theta_1 + \theta_2 \alpha^2)} \left(\overline{\phi} + E[\pi] \right), \tag{9}$$

which makes use of the relationship $\overline{W} = \overline{w} + E[p]$ and of the definition of the real wage premium, $\overline{\phi} \equiv \overline{w} - w^c$. Noting that $E[\pi] = E[si] = \Lambda_1$, eliminating $E[\pi]$ from (9) gives Λ_1 in equilibrium:

$$\Lambda_1 = \frac{\mu_2 \alpha^2}{\mu_1 + \sigma_s^2 (\theta_1 + \theta_2 \alpha^2)} \overline{\phi}. \tag{10}$$

Setting $\mu_1 = \theta_1 = I$, $\mu_2 = \theta_2 = 1$, and $\sigma_s^2 = 0$ replicates the result in CL.

The solution for Λ_2 is

$$\Lambda_2 = \frac{\alpha \theta_2}{(1 + \sigma_s^2)(\theta_1 + \theta_2 \alpha^2)}. \tag{11}$$

3.2 Solution to Unions' Problem

Unions solve a standard optimization problem, setting nominal wages based on expectations of future inflation. Hence, union j minimizes (1) subject to the central bank's reaction function (9) and taking other unions' wages as given. Making use of the fact that union j's unemployment rate is given by

$$u_j \equiv \frac{L_j - L_j^d}{L_j} = \alpha \left(W_j - \pi - p_{-1} - w^c \right) + \gamma n \left(W_j - \overline{W} \right), \tag{12}$$

the solution to union j's problem, after imposing symmetry and rearranging, yields the following expression for the economy-wide real wage premium:

$$\overline{\phi} = \frac{\mu_2 \alpha^2 (n-1) + \lambda n}{\alpha \left[\chi \left(\alpha \left(\mu_2 \alpha^2 (n-1) + \lambda n \right) + \gamma n (n-1) \left(\lambda + \mu_2 \alpha^2 \right) \right) + \Phi \frac{\mu_2^2 \alpha^3}{\lambda} \right]} \tag{13}$$

with $\lambda \equiv \mu_1 + \sigma_s^2 \left(\theta_1 + \theta_2 \alpha^2 \right)$ and $\Phi \equiv \xi \left(1 + \sigma_s^2 \right) + \chi \alpha^2 \sigma_s^2$.

The expected equilibrium unemployment rate in the economy is given by

$$E[u] = \alpha \overline{\phi}, \tag{14}$$

while average inflation is given by (10). Quick inspection of (13), (14), and (10) reveals that the real wage premium, the unemployment rate, and inflation are strictly positive.

4 Discussion

How are the real wage premium and average unemployment affected by the presence of Brainard uncertainty? The following proposition provides the answer:

Proposition 1 *(i) For sufficiently small μ_1, χ and sufficiently large n, θ_1, θ_2 , μ_2, ξ, an increase in Brainard uncertainty (a higher σ_s^2) monotonically raises the equilibrium real wage premium and average unemployment. (ii) For sufficiently large μ_1, χ and sufficiently small n, θ_1, θ_2 , μ_2. α, ξ, an increase in Brainard uncertainty (a higher σ_s^2) lowers the equilibrium real wage premium and average unemployment for small values of σ_s^2 and raises the equilibrium real wage premium and average unemployment for large values of σ_s^2. This effect becomes negligible as $n \to \infty$.*

Proof. *See appendix.* ■

With Brainard uncertainty unions face a trade-off between their real wage objective and unemployment stability. They are able to reduce the variance of inflation and unemployment at the expense of lower wages (which also implies lower mean inflation).

Thus case (ii) highlights that there are two effects at work—the 'mean effect' and the 'variance effect'. On the one hand, unions are aware that increased uncertainty makes the central bank more cautious, leading to a reduction in mean inflation. Given that they have some monopoly power and they are Stackelberg leaders in the policy game, they want to exploit the central bank's restraint by increasing nominal wages. In other words, unions know that the central bank will inflate away less of any nominal wage increase because it fears the implications of strong activist policy.

On the other hand, greater uncertainty, for low values of σ_s^2 and any given value of $\overline{\phi}$, increases the variance of inflation and unemployment, forcing unions to show wage restraint. In case (ii) the variance effect dominates the mean effect for small σ_s^2 and vice versa for large σ_s^2. In case (i) the mean effect always dominates the variance effect.

Whether case (i) or case (ii) prevails depends on the values of the other model parameters. Case (i) obtains when unions care sufficiently about inflation relative to real wages and unemployment (high ξ and low χ) or when the central bank cares little about mean inflation relative to all its other objectives (low μ_1 and high μ_2, θ_1, θ_2). In this case the mean effect is so strong that it always dominates the variance effect.

Furthermore, the mean effect globally dominates the variance effect when the number of unions n is large. An increase in the number of unions has two opposite effects: each union's market power falls (since the elasticity of labor demand facing each union rises), putting downward pressure on real wages—the 'competition effect'—but each union internalizes less the extent to which its own actions affect aggregate prices, putting upward pressure on real wages—the 'strategic effect.'[5] Both of these effects serve to strengthen the mean effect outlined above, increasing the range of parameter values for which case (i) applies. As the number of unions goes to infinity, each union's monopoly power vanishes and the real wage premium disappears. Unsurprisingly, the wage premium is then independent of σ_s^2 and of unions' and central bank's preference parameters.

Note how Proposition 1 generalizes the results contained in Lawler (2002). His model assumes a single monopoly union whose preferences do *not* include inflation. Setting $n = 1$, $\xi = 0$, $\chi = 1$, $\mu_1 = \theta_1 = \eta$, and $\mu_2 = \theta_2 = 1$ equation (13) becomes

$$\overline{\phi} = \frac{\left[\eta + \sigma_s^2\left(\eta + \alpha^2\right)\right]^2}{\alpha^2\left(\left[\eta + \sigma_s^2\left(\eta + \alpha^2\right)\right]^2 + \sigma_s^2\alpha^4\right)},$$

which is analogous to Lawler's expression. With these parameter values the real wage premium is indeed U-shaped, attaining a minimum at $\sigma_s^2 = \eta/\left(\alpha^2 + \eta\right)$. Lawler concludes that this is a general result since he assumes that, "the key results derived

[5] The joint presence of these two effects gives rise to the well documented hump-shaped relation between the degree of centralization of wage bargaining and real wages. See Calmfors and Driffill (1988), Calmfors (1993), and Cukierman and Lippi (1999).

below extend to a multi-union setting providing each union is sufficiently large to have some impact on macreconomic outcomes." [p. 37] Proposition 1 above shows that Lawler's conclusion is rather more specific.

The above point is not merely a theoretical curiosity. There is good reason to believe that case (i) is actually the empirically dominant one. For reasonable parameter values it only takes a small number of unions to generate case (i). For example, when $\alpha = 0.7$, $\gamma = 1$, $\mu_1 = \theta_1 = 2$, $\mu_2 = \theta_2 = 1$, $\xi = 0.4$ and there is only one all-encompassing monopoly union, the real wage premium is monotonically increasing in σ_s^2, viz. case (i) obtains. One may well argue that $\xi = 0.4$ is too high. Lowering it to 0.1 breaks the monotonicity of $\overline{\phi}$ (e.g. case (ii)) but as soon as there are two or more unions, the monotonicity is restored. Since most economies are populated by several unions, it is very difficult to generate case (ii) unless one assumes extreme values for some of the parameters.

Proposition 1 is also very different from the argument advanced by Grüner (2002), Grüner et al. (2005), and Sørensen (1991). In their models uncertainty about central bank preferences unambiguously *reduces* wages, average inflation, and unemployment. The central bank does not face parameter uncertainty and therefore sets optimal policy in a standard certainty-equivalent framework. Once the central bank reaction function is obtained, the associated elasticities are assumed to be random. This is supposed to capture the notion that unions are unsure about the central bank's preferences. Here, on the other hand, the central bank's control of the monetary policy process is imprecise which tempers the response to wage claims and thus leads to *higher* wages and *lower* unemployment.

Several authors have argued that multiplicative uncertainty in the policy transmission enhances welfare because it makes the policymaker more cautious and thereby reduces the inflation bias.[6] Proposition 1 shows that an increase in multiplicative uncertainty typically increases the wage premium, leading to a bigger unemployment distortion. This, in turn, *raises* the incentive for the central bank to engineer an inflation surprise. The reason why Proposition 1 departs from previous authors' conclusions is that their analysis is based on an invariant output distortion. With monopolistic unions the output (or unemployment) distortion is endogenous and thus becomes a function of the economic environment and therefore also of the degree of uncertainty.[7]

If the central bank loss function (6) is taken to be the appropriate social welfare function, then an increase in Brainard uncertainty has an ambiguous effect on welfare for one can show that $\partial E[\pi]/\partial\sigma_s^2 < 0$, $\partial E[u]/\partial\sigma_s^2 \lesseqgtr 0$, $\partial Var[u]/\partial\sigma_s^2 \lesseqgtr 0$, and

[6] For example, Swank (1994, p. 30) argues that, "in a stochastic framework, it appears that an increase in multiplicative uncertainty about policy effects on money growth reduces the policymaker's incentive to create inflation surprises and increases welfare." See also Pearce and Sobue (1997) and Schellekens (2002) for a similar sentiment.

[7] Output and unemployment, as modelled here, are inversely related. It is easy to rephrase the present model in terms of output instead of unemployment.

$\partial Var[\pi]/\partial\sigma_s^2 \lesseqgtr 0$. Hence, caution resulting from Brainard uncertainty is not, in general, welfare enhancing.

The following result summarizes the comparative statics with regard to the central bank's preference parameters:

Proposition 2 *An increase in μ_1, θ_1, and θ_2 and a decrease in μ_2 all raise the equilibrium real wage premium and average unemployment. These effects become negligible as $n \to \infty$.*

Proof. *Differentiating (13) with respect to μ_1, θ_1, θ_2, and μ_2 gives*

$$\frac{\partial\overline{\phi}}{\partial\mu_1} = Y > 0, \qquad \frac{\partial\overline{\phi}}{\partial\theta_1} = \sigma_s^2 Y > 0, \qquad \frac{\partial\overline{\phi}}{\partial\theta_2} = \sigma_s^2\alpha^2 Y > 0,$$

where

$$Y \equiv \frac{\mu_2\left[\chi\alpha\gamma n(n-1) + \Phi\frac{\mu_2\alpha^2}{\lambda}\left(2n + \frac{\mu_2\alpha^2(n-1)}{\lambda}\right)\right]}{\left[\chi\left(\alpha\left(\mu_2\alpha^2(n-1)+\lambda n\right)+\gamma n(n-1)\left(\lambda+\mu_2\alpha^2\right)\right)+\Phi\frac{\mu_2^2\alpha^3}{\lambda}\right]^2} > 0,$$

and

$$\frac{\partial\overline{\phi}}{\partial\mu_2} = -\frac{\chi\alpha\gamma n(n-1)\lambda + \mu_2\alpha^2\left(2+\mu_2\alpha^2(n-1)\right)}{\left[\chi\left(\alpha\left(\mu_2\alpha^2(n-1)+\lambda n\right)+\gamma n(n-1)\left(\lambda+\mu_2\alpha^2\right)\right)+\Phi\frac{\mu_2^2\alpha^3}{\lambda}\right]^2} < 0.$$

■

The intuition for this result is as follows. When μ_1 is high, the monetary authority places a lot of emphasis on hitting the inflation target. She will therefore be loath to inflate away the high wages set by the unions. The latter take advantage of this, and the real wage premium will be relatively high. Conversely, when μ_2 is high, the monetary authority has a strong preference for low *average* unemployment. It is willing to accept higher inflation in order to erode the excessive nominal wages set by the unions. The real wage premium will be relatively small, as unions know that high wages are inflated away.

The effects of θ_1 and θ_2 on $\overline{\phi}$ are similarly intuitive. When θ_1 (θ_2) increases, the policymaker places more emphasis on avoiding *unforecastable* deviations in inflation (unemployment) from target. A higher σ_s^2 implies that monetary policy itself injects more uncertainty into the system. Thus, fearing the uncertain consequences of its own actions, the monetary authority becomes reluctant to generate high inflation in response to high nominal wages. As a result, the real wage premium will be relatively large.

When $\sigma_s^2 = 0$, the real wage premium no longer depends on θ_1 and θ_2. Likewise, when $n \to \infty$, unions neglect the effect of their own actions on inflation so that the wage premium becomes independent of the policymaker's preferences.[8]

[8] The benefit of using the generalized loss function for the government should be clear by now. The conventional loss function, such as the one used by CL, imposes $\mu_1 = \theta_1 = \eta$ and $\mu_2 = \theta_2 = 1$ and obscures the opposing effects of μ_2 and θ_2 on the real wage premium.

Proposition 2 is important when assessing the validity of the existing literature on caution and conservatism in monetary policy as conventional results are overturned when the output/unemployment distortion is endogenized. Schellekens (2002), for example, argues that,

> "delegation to a conservative central banker does not entail suboptimal output stabilization if conservatism is not arbitrarily restricted to the notion of weight-conservatism. Alternative forms of conservatism, such as stability-conservatism and target-conservatism, reduce the inflationary bias without distorting the stabilization of output.[9] [..] *Any* delegation scheme which improves or removes the credibility problem of monetary policy reduces at the same time the variability of output (and of inflation), if the transmission of monetary policy is subject to multiplicative uncertainty.
>
> The overall theoretical implication is thus, surprisingly, that delegation based on optimal notions of conservatism should not only lead to lower inflation but also to less variable output." [p. 173]

This statement is questionable on two accounts. First, Schellekens claims that delegation of monetary policy to a central banker with an exclusive concern for stability leads to the second-best outcome. This is modelled by assuming that the central bank has preference parameters θ_1^* and θ_2^* which are greater than society's θ_1 and θ_2 by a factor κ^*, e.g. $\theta_1^* = \kappa^*\theta_1$ and $\theta_2^* = \kappa^*\theta_2$ with $\kappa^* > 1$. He shows that a higher κ^* unambiguously reduces the inflation bias while leaving the stabilization component (Λ_2) unchanged. Hence, choosing $\kappa^* \to \infty$ eliminates the inflation bias without distorting the stabilization component. However, this result crucially hinges on a constant output distortion. In the model presented here, delegating monetary policy to a central banker with κ^* implies that average unemployment becomes

$$E[u] = \alpha\overline{\phi} = \frac{\mu_2\alpha^2(n-1) + \lambda^* n}{\left[\chi\left(\alpha\left(\mu_2\alpha^2(n-1) + \lambda^* n\right) + \gamma n(n-1)\left(\lambda^* + \mu_2\alpha^2\right)\right) + \Phi\frac{\mu_2^2\alpha^3}{\lambda^*}\right]} \tag{15}$$

with $\lambda^* = \mu_1 + \kappa^*\sigma_s^2\left(\theta_1 + \theta_2\alpha^2\right)$. Proposition 1(i) showed that $\partial\overline{\phi}/\partial\sigma_s^2 > 0$, so it is straight-forward to see that $\partial\overline{\phi}/\partial\kappa^* > 0$. Thus, delegating policy to a stability-conservative central banker may well reduce or eliminate the inflation bias but at

[9] Weight-conservatism refers to the relative preference for inflation versus output stabilization. This is the "traditional" definition of conservatism, as in Rogoff (1985). Schellekens (2002) introduces the notions of stability-conservatism and target-conservatism based on the generalized quadratic objective function. Stability-conservatism is defined as a relative preference for nominal and real stability and corresponds to a higher θ_1 and θ_2. A central banker is said to be target-conservative if, relative to the government, she places more emphasis on hitting the inflation target than the output target. This corresponds to a relatively high μ_1 and a relatively low μ_2.

the cost of higher average unemployment. The second-best outcome is therefore not generally attainable.

Second, contrary to Schellekens' claim, stability- and target-conservatism may adversely affect output/unemployment *variability*, when the output/unemployment distortion is endogenous. Consider the variance of unemployment, which, in equilibrium, is given by

$$
\begin{aligned}
Var\left[u\right] &= \left(\frac{\mu_2 \alpha^3 \overline{\phi}}{\lambda}\right)^2 \sigma_s^2 \qquad (16) \\
&+ \left(1 + \left(1+\sigma_s^2\right)\left(\frac{\theta_2 \alpha^2}{\left(1+\sigma_s^2\right)\left(\theta_1 + \theta_2 \alpha^2\right)}\right)^2 - \frac{2\theta_2 \alpha^2}{\left(1+\sigma_s^2\right)\left(\theta_1+\theta_2\alpha^2\right)}\right)\sigma_\varepsilon^2 .
\end{aligned}
$$

According to Proposition 2 more inflation stability-conservatism (higher θ_1), for example, increases the real wage premium, thereby increasing the unemployment distortion. Equation (16) indicates that this *may* also lead to higher unemployment variability in equilibrium.

5 Conclusion

It was shown that when there are non-atomistic wage setters, an increase in multiplicative uncertainty typically raises the real wage premium and unemployment and hence may reduce welfare. This suggests that policy caution resulting from Brainard uncertainty does not increase welfare. Furthermore, since central bank preferences also affect real variables, delegating policy to an independent central banker with an optimal degree of conservatism cannot, in general, deliver a second-best outcome. These results warn of drawing quick policy conclusions when the model does not properly specify the private sector.

The present model is limited by its static nature. A dynamic analysis would be able to account for the possibility that optimality of monetary policy under multiplicative uncertainty calls for greater aggressiveness and therefore a worsening of the inflation bias.[10] Furthermore, a richer environment, such as a New Keynesian model with nominal wage rigidities, would yield further insights and set the stage for a thorough empirical analysis. These challenges are left for the future.

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6 Appendix

Derivation of Central Bank's Reaction Function

By substituting (5), (7), and (8) into (6), the central bank's objective function may be rewritten as

$$\begin{aligned} L &= \mu_1 \Lambda_1^2 \\ &+\theta_1 \left(\Lambda_1^2 \sigma_s^2 + \Lambda_2^2 \sigma_\varepsilon^2 \left(1+\sigma_s^2\right)\right) \\ &+\mu_2 \left(\alpha \overline{W} - \alpha \Lambda_1 - \alpha p_{-1} - \alpha w^c\right)^2 \\ &+\theta_2 \left(\Lambda_1^2 \alpha^2 \sigma_s^2 + \Lambda_2^2 \alpha^2 \sigma_\varepsilon^2 \left(1+\sigma_s^2\right) + \sigma_\varepsilon^2 - 2\alpha \Lambda_2 \sigma_\varepsilon^2\right) \end{aligned}$$

which makes use of the statistical relationship $Var\left[s\varepsilon\right] = E\left[\varepsilon\right] Var\left[s\right] + E\left[s\right] Var\left[\varepsilon\right] + Var\left[\varepsilon\right] Var\left[s\right]$ (since ε and s are independent).

Differentiating the central bank's objective function with respect to Λ_1 and setting equal to zero gives the central bank's first-order condition:

$$\begin{aligned} \frac{\partial L}{\partial \Lambda_1} &= 2\mu_1 \Lambda_1 + 2\theta_1 \Lambda_1 \sigma_s^2 - 2\mu_2 \alpha \left(\alpha \overline{W} - \alpha \Lambda_1 - \alpha p_{-1} - \alpha w^c\right) \\ &+2\theta_2 \Lambda_1 \alpha^2 \sigma_s^2 = 0 \end{aligned}$$

which, by making use of the relationships $\overline{W} = \overline{w} + E\left[p\right]$, $\overline{\phi} \equiv \overline{w} - w^c$, and $E\left[\pi\right] = \Lambda_1$, may be solved for Λ_1, equation (10) in the text.

Derivation of Real Wage Premium

Substituting (12) into (1), the union's minimization problem becomes

$$\begin{aligned} &\min_{W_j} E\left\{-2\left(W_j - \pi - p_{-1}\right)\right. \\ &\left.+\chi\left[\alpha\left(W_j - \pi - p_{-1} - w^c\right) + \gamma n\left(W_j - \overline{W}\right)\right]^2 + \xi \pi^2\right\}, \end{aligned}$$

which make use of $w_j = W_j - E\left[p\right] = W_j - E\left[p\right] + p_{-1} - p_{-1} = W_j - E\left[\pi\right] - p_{-1}$.

Replacing π with (7) and (8), differentiating the above expression with respect to W_j, and setting equal to zero gives the union's first-order condition:

$$\begin{aligned} \frac{\partial \Omega_j}{\partial W_j} &= E\left\{-1 + s\frac{\partial \Lambda_1}{\partial W_j}\right\} \\ &+E\left\{\chi u_j \left(\alpha - \alpha s \frac{\partial E\left[\pi\right]}{\partial W_j} + \gamma\left(n-1\right)\right)\right\} \\ &+E\left\{\xi \pi s \frac{\partial \Lambda_1}{\partial W_j}\right\} = 0 \end{aligned}$$

Making use of the following relationship, $\phi_j = w_j - w^c = W_j - E[p] - w^c = W_j - E[\pi] - p_{-1} - w^c$ and defining $Z \equiv 1 - \partial\Lambda_1/\partial W_j$, the above FOC can be simplified to

$$-Z + \chi\left[\alpha\phi_j + \gamma n\left(\phi_j - \overline{\phi}\right)\right](\alpha Z + \gamma(n-1)) + (1-Z)\Lambda_1\left(\xi\left(1+\sigma_s^2\right) + \chi\alpha^2\sigma_s^2\right) = 0.$$

Imposing symmetry $\left(\phi_j = \phi_i = \overline{\phi}\right)$ gives

$$-Z + \chi\alpha\overline{\phi}(\alpha Z + \gamma(n-1)) + (1-Z)\Lambda_1\left(\xi\left(1+\sigma_s^2\right) + \chi\alpha^2\sigma_s^2\right) = 0$$

which can be solved for $\overline{\phi}$ to give

$$\overline{\phi} = \frac{Z - (1-Z)\Lambda_1(\xi(1+\sigma_s^2) + \chi\alpha^2\sigma_s^2)}{\chi\alpha(\alpha Z + \gamma(n-1))}.$$

Substituting for Z and Λ_1 and simplifying gives the equilibrium real wage premium, equation (13) in the text.

Proof of Proposition 1
Differentiating (13) with respect to σ_s^2 yields

$$\begin{aligned}\frac{\partial\overline{\phi}}{\partial\sigma_s^2} &= \frac{1}{D^2}\left\{\left(\theta_1 + \theta_2\alpha^2\right)\mu_2\alpha^3\left[\chi\gamma n(n-1)\right.\right. \\ &\quad \left. + \left(\xi\left(1+\sigma_s^2\right) + \chi\alpha^2\sigma_s^2\right)\frac{\mu_2\alpha}{\lambda}\left(2n + \frac{\mu_2\alpha^2(n-1)}{\lambda}\right)\right] \\ &\quad \left. -\frac{\mu_2^2\alpha^4}{\lambda}\left(\xi + \chi\alpha^2\right)\left(\mu_2\alpha^2(n-1) + \lambda n\right)\right\}\end{aligned}$$

where D is the denominator of (13).

As D^2 is always positive, the sign of the derivative is equal to the sign of the numerator. Rewrite the numerator as

$$\begin{aligned}&\mu_2\alpha^3 n\left[\left(\theta_1 + \theta_2\alpha^2\right)\chi\gamma(n-1) - \mu_2\alpha\left(\xi + \chi\alpha^2\right)\right] \\ &+\frac{\mu_2^2\alpha^4}{\lambda}\left\{\left(\xi\left(1+\sigma_s^2\right) + \chi\alpha^2\sigma_s^2\right)\left(2n + \frac{\mu_2\alpha^2(n-1)}{\lambda}\right)\left(\theta_1 + \theta_2\alpha^2\right)\right. \\ &\left. - \left(\xi + \chi\alpha^2\right)\mu_2\alpha^2(n-1)\right\}.\end{aligned} \tag{A1}$$

The first term is a constant, independent of σ_s^2, which can be either positive or negative. The term in curly brackets is monotonically increasing in σ_s^2. Hence, for sufficiently large σ_s^2 the whole expression becomes positive.

Therefore, if $\partial\overline{\phi}/\partial\sigma_s^2 > 0$ at $\sigma_s^2 = 0$, then $\partial\overline{\phi}/\partial\sigma_s^2 > 0$ for all σ_s^2. If $\partial\overline{\phi}/\partial\sigma_s^2 < 0$ at $\sigma_s^2 = 0$, then $\overline{\phi}$ displays a U-shape as σ_s^2 increases with a minimum at some finite σ_s^2.

At $\sigma_s^2 = 0$, (A1) becomes

$$\mu_2\alpha^3 n \left[\left(\theta_1 + \theta_2\alpha^2\right)\chi\gamma\left(n-1\right) - \mu_2\alpha\left(\xi + \chi\alpha^2\right)\right]$$
$$+\frac{\mu_2^2\alpha^4}{\mu_1}\left\{\xi\left(2n + \frac{\mu_2\alpha^2\left(n-1\right)}{\mu_1}\right)\left(\theta_1 + \theta_2\alpha^2\right) - \left(\xi + \chi\alpha^2\right)\mu_2\alpha^2\left(n-1\right)\right\}.$$

This expression is negative for sufficiently large μ_1, χ or for sufficiently small n, θ_1, θ_2 , μ_2, ξ.

From (14) it follows that the qualitative relation between unemployment and σ_s^2 $(\partial E\left[u\right]/\partial\sigma_s^2)$ is the same as the qualitative relation between the real wage premium and σ_s^2 $(\partial\overline{\phi}/\partial\sigma_s^2)$.