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CAN INTERNATIONAL MONETARY POLICY COOPERATION BE COUNTERPRODUCTIVE?

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This paper demonstrates that increased international monetary cooperation may actually be counterproductive. The potential problem is that cooperation between central banks *may* exacerbate the credibility problem of central banks vis-à-vis the private sector. Coordinated monetary expansion yields a better output/inflation trade-off than unilateral expansion because it does not induce exchange rate depreciation. Wage setters realize that the incentives to inflate are greater in a cooperative regime, and thus time-consistent nominal wage rates are higher. Cooperation does improve responses to disturbances. Thus, a cooperative regime which contains institutional constraints on systematic inflation is definitely superior.

1. Introduction

Schemes to increase coordination among central banks of employment and inflation-rate stabilization policies have received a great deal of attention.[1] Unfortunately, most analyses focus entirely on how central banks might cooperate to offset unanticipated disturbances, and devote little or no consideration to the problem of systematically maintaining low rates of inflation. The present paper is an effort to provide a simple macroeconomic framework in which to examine both issues. Within the context of a two-country model of a managed floating exchange rate system, we simultaneously analyze the strategic interactions of sovereign monetary authorities across countries, and the strategic interactions of private agents and the monetary authorities within a given country.

The main result of this paper is that, contrary to the usual conclusion (and presumption) of earlier analyses, increased monetary policy cooperation

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[1]Cooper (1969) and Hamada (1976) were the first to analyze the strategic interactions of two (or more) governments in conducting monetary stabilization policy. More recently, Jones (1982, 1983) as well as Canzoneri and Gray (1985) have examined some game-theoretic aspects of monetary policy under fixed and flexible exchange rates. The above analyses do not incorporate rational expectations. Other recent multi-country analyses of monetary policy include Carlozzi and Taylor (1984), Henderson (1984), Macedo (1983), McKinnon (1982), Miller and Salmon (1983), and Sachs (1983).

between two governments does not automatically increase welfare in either country.[2] In fact, welfare in one or both countries may be higher when central banks conduct their monetary policies independently. The potential danger with inter-central bank cooperation is that it can exacerbate the credibility problem of central banks vis-à-vis the private sector. One reason for such a credibility problem is that the central bank may be tempted to try to exploit the existence of nominal wage contracts to systematically raise employment.[3] Of course, in a time-consistent equilibrium, wage inflation will be high enough so that the central bank's efforts will be futile. International monetary cooperation may raise the rate of wage inflation because wage setters recognize that a noncooperative regime contains a built-in check on each central bank's incentives to inflate. The reason is that when a central bank expands its money supply unilaterally, it causes its country's real exchange rate to depreciate thereby reducing the employment gains and increasing the CPI inflation costs. Cooperation may remove this disincentive to inflate, and thus raise time-consistent nominal wage growth. A cooperative regime does produce better responses to supply shocks or relative shifts in aggregate demand; that is to say, it reduces the variance of the social welfare function around its mean market-determined value. But monetary policy cooperation is unambiguously beneficial only in institutional frameworks which eliminate or ameliorate the central banks' credibility problem vis-à-vis the private sector.

Except for the fact that it incorporates rational expectations (cum wage contracting), the stochastic, two-good, two-country model we employ is quite similar to ones which have been used to characterize the benefits of intergovernmental cooperation. Nominal wage contracts, negotiated a period in advance and only partially indexed to the current price level, provide the fulcrum for monetary policy (though the basic point of the analysis extends to alternative non-neutralities). The details of the underlying macro model are relegated to appendix A, since they are not needed to express the main ideas. Section 2 describes the home and foreign welfare functions, which depend on own employment and CPI inflation. Section 3 details the objectives of wage setters, as well as the nature of a time-consistent equilibrium. Section 4 describes the cross-effects of home and foreign monetary policy; the real exchange rate plays a key role here. The main

[2]An important exception is Vaubel (1983), who has independently suggested that currency competition under floating rates may lead to lower inflation. We will not ask here how a cooperative regime might be implemented. Hamada (1976) stresses that the problem may best be thought of as one in which the central banks cooperate to construct a regime with the best possible (self-enforcing) noncooperative equilibrium.

[3]The analysis of the strategic interactions of private agents and the monetary authorities within a given country is based on Phelps (1967), Kydland and Prescott (1977), Barro and Gordon (1983a) and Rogoff (1985). It is important to recognize that the bank's actions should be interpreted as maximizing social welfare given the institutional framework within which it operates. See sections 3 and 8 below.

result is illustrated in section 5. Section 6 formally derives the stochastic equilibrium path of the world economy when central banks conduct stabilization unilaterally, and are unable to guarantee to wage setters that they will not try systematically to raise employment. Section 7 contrasts the results of section 6 with social welfare under a regime in which central banks again lack credibility with wage setters, but are able to cooperate with each other in conducting stabilization policy. Section 8 stresses that an optimal cooperative regime — one which contains institutional constraints on systematic inflation — is definitely superior to any noncooperative regime.

2. Domestic and foreign social objective functions

Each central bank attempts to minimize a social loss function which depends on deviations of own-country employment and inflation from their optimal (socially-desired) values:[4]

$$\Lambda_t=(n_t-\tilde{n})^2+\chi(\pi_{It}-\tilde{\pi}_I)^2, \tag{1a}$$

$$\Lambda_t^*=(n_t^*-\tilde{n}^*)^2+\chi(\pi_{It}^*-\tilde{\pi}_I^*)^2, \tag{1b}$$

where Λ (Λ^*) is the home (foreign) social loss function. Star superscripts denote foreign country variables, t subscripts denote time, and lower case letters represent logarithms. (Henceforth, we will discuss only domestic variables and equations in circumstances where discussion of their foreign counterparts is superfluous.) Employment is given by n, and π_I is the rate of consumer price level inflation, e.g. $\pi_{It}=(p_I)_t-(p_I)_{t-1}$, where the index p_I [defined in eq. (16) of appendix A] includes both the home- and foreign-produced good. The socially-preferred values of n and π_I are denoted by $\tilde{n}$ and $\tilde{\pi}_I$. χ is the relative weight which society places on inflation stabilization versus employment stabilization.[5] As with all of the parameters of the model of appendix A, χ is the same for both countries; also, $\tilde{\pi}_I=\tilde{\pi}_I^*$, and $\tilde{n}=\tilde{n}^*$. This symmetry greatly simplifies the algebra, but is not essential to the analysis. The objective functions (1) are static, but because wage contracts

[4]A similar specification of the social loss function is used by Barro and Gordon (1983a), and by Kydland and Prescott (1977).

[5]In most rational expectations macroeconomic models, inflation rate shocks enter the social loss function only indirectly through their effects on employment. It is indeed difficult to strongly justify including the level of inflation as a separate term in Λ. To close the model, however, it is only necessary that the weight on inflation be nonzero. (It is also necessary that Λ be strictly convex in π_I.) Some costs of perfectly anticipated inflation include the administrative costs of posting new prices, the costs of adjusting the tax system to be fully neutral with respect to inflation, and the costs incurred because high rates of inflation force private agents to economize on their holdings of noninterest-bearing money. The optimal rate of inflation may nevertheless be nonzero; it may be optimal to make some use of the seignorage tax when other methods of taxation are also distortionary. See Phelps (1973).

are for one period, the results below would be unchanged even with multiperiod objective functions.[6]

3. The conflict between wage setters and the central banks

The tension between wage setters and the central bank within each country derives from the assumption that $\tilde{n}$, society's target employment rate, is greater than $\bar{n}$, wage setters' target employment rate. Possible factors which might cause equilibrium employment $\bar{n}$ to be too low include income taxation, unemployment insurance and monopolistic unions; see Barro and Gordon (1983a). Income taxation, for example, drives a wedge between private and social marginal product. While an individual would not want to be alone in being fooled by the central bank into working an extra hour (since he would only receive an infinitesimal share of the benefits from his extra taxes), he might be better off if everyone were to work an extra hour (since he would share in the benefits from everyone's taxes).

Of course, the monetary authorities cannot systematically raise the level of employment. In equilibrium, base nominal wage rates are set at a sufficiently high level so that, in the absence of disturbances, the central bank will not *choose* to inflate the money supply beyond the point consistent with wage setters' desired real wage. At this sufficiently high level of inflation the central bank finds that the marginal utility gain from inflating (further) to raise employment above wage setters' desired level is fully offset by the marginal disutility from the added inflation.[7] Note that each individual group of wage setters is indeed concerned with the inflation rate, just as society is. But because the impact of an individual firm's contract on aggregate inflation is small, they have little incentive to temper their nominal wage increases. Thus, the equilibrium is Nash.

Obviously, if the labor market distortion can be removed at low cost, then there is no problem. A second-best equilibrium could be attained if the central bank is able credibly to promise not to systematically inflate. The problem is how to design a system to enforce such a promise without constraining the ability of the central bank to offset unanticipated shocks. For example, if it were possible to anticipate every type of disturbance, one

[6]Even with one-period contracts, it would be necessary to explicitly allow for multi-period objective functions in order to analyze reputational equilibria; see Barro and Gordon (1983b) or Canzoneri (1985). Sachs (1983) examines monetary policy cooperation in an interesting dynamic setting, and Miller and Salmon (1983) examine dynamic games in a very general dynamic open-economy model. The main point of the present paper can be expressed in a model with more dynamic elements.

[7]Phelps (1967) and Kydland and Prescott (1977) demonstrate why a time-consistent macroeconomic equilibrium might be characterized by stagflation. While we focus here on labor market distortions, there are other factors which may cause the time-consistent rate of inflation to be too high. Examples include seignorage and the existence of nominal government debt; see Barro and Gordon (1983a).

could write a law specifying an optimal contingent path of the money supply. We shall return to this issue in section 8.

4. The macro model and the linkages between the two central bank objective functions

Aside from the credibility problems which the monetary authorities face vis-à-vis the private sector, there is also scope for strategic interactions between the two central banks. Although it is possible to develop alternative linkages, the analysis here focuses on those which arise in the rational expectations Mundell–Fleming model of appendix A. In that model, each country produces a different good; the two goods enter with equal weights into the CPI in both countries. The demand for each country's good depends on its relative price, the real interest rate, and income at home and abroad. Only home (foreign) residents hold the home (foreign) money; the demand for real balances is a function of real income and the nominal interest rate. Residents of both countries hold both home and foreign bonds, which are perfect substitutes.

One can see that the real exchange rate is the key link between the two central bank objective functions by substituting eqs. (16), (17) and (18) of appendix A into eqs. (1):

$$\Lambda_t = [z_t/\alpha + \gamma(p_t - \bar{w}_t) - \tau q_t - (\tilde{n} - \bar{n})]^2$$

$$+ \chi[p_t - p_{t-1} + 0.5(q_t - q_{t-1}) - \tilde{\pi}_I]^2, \tag{2a}$$

$$\Lambda_t^* = [z_t/\alpha + \gamma(p_t^* - \bar{w}_t^*) + \tau q_t - (\tilde{n}^* - \bar{n}^*)]^2$$

$$+ \chi[p_t^* - p_{t-1}^* - 0.5(q_t - q_{t-1}) - \tilde{\pi}_I^*]^2, \tag{2b}$$

where p is the home-currency price of the home good, p^* is the foreign-currency price of the foreign good, and q is the real exchange rate: $q \equiv e + p^* - p$ (e is the home-currency price of foreign currency). $\bar{w}$ ($\bar{w}^*$) is the home (foreign) base nominal wage rate, and z is a supply shock common to both countries.

The first term in Λ represents squared deviations of home employment from its socially-desired value. It depends on the productivity disturbance z, the unanticipated movement in the real wage $\bar{w} - p$, and the difference between society's and wage setters' target levels of employment, $\tilde{n} - \bar{n}$. The real exchange rate q also enters because wages are indexed to the CPI, which includes the foreign good. A similar term in q would arise if, as in the model of Daniel (1981), the foreign good entered as an intermediate good into the domestic production function. The second term in the social objective function is the squared difference between the actual rate of CPI inflation and society's target rate. Again, the real exchange rate enters.

5. Cooperation can be counterproductive

We have discussed (a) why the central banks cannot systematically alter the mean level of employment in a time-consistent equilibrium, and (b) how the real exchange rate links the objective functions of the two central banks. These are the two key elements of our main result: a cooperative regime may be characterized by systematically higher inflation rates than a noncooperative regime.

This result, which will be proven formally below, can be seen most simply by assuming that there are no disturbances and that the cooperative regime attains the symmetric point on the central banks' contract curve. (Due to the symmetry of the model, this point is achieved if the two central banks credibly agree to fix their exchange rate.) Note that each central bank has two objectives but only one instrument at its disposal: the money supply.[8] Once base wage rates are set, any unilateral effort by either central bank to inflate will cause its country's real exchange rate to depreciate (except in the case of complete wage indexation).[9] By inspection of eqs. (2), we see that this concomitant depreciation puts a check on each central bank's incentive to expand their money supply. A real depreciation directly raises CPI inflation, and tends to lower employment if (a) wages are indexed to the CPI, or if (b) the foreign good enters as an intermediate good in the home production function. Wage setters recognize the tempering influence of the real exchange rate when setting their base nominal wage rates.

This tempering influence is not present in the cooperative regime, since each central bank can count on the other to match any money supply increase. Cooperation thus forces wage setters to set a higher rate of nominal wage growth in order to ensure that the central banks will ratify their target real wage. Since monetary policy does not end up having any systematic effect on employment in either regime, the only thing accomplished by central bank to central bank cooperation is to raise inflation. Of course, as we shall see below, one can construct counterexamples to this counterexample: cooperation can also be productive.

[8]See appendix A. We are restricting our attention to contemporaneous money supply feedback rules since, in the setup of the text, 'prospective' (lagged) feedback rules [see Canzoneri, Henderson and Rogoff (1983)] are not time consistent; see Rogoff (1985).

[9]It would, of course, be attractive to extend the present model to allow for an endogenous determination of the coefficient of wage indexation, β. For the full information setup of the text, one can show that individual groups of wage setters would choose $\beta = 0$ if β is bounded between zero and one. Wage setters have no need to worry about aggregate goods market demand and money demand disturbances, because these are fully offset by the central banks. However, wage setters want the central banks to allow some price-level movement in response to productivity shocks in order to stabilize employment around the level which would arise if nominal wages were fully flexible. (See appendix A.) But because the central banks also care about price-level stability, they do not allow sufficient price-level movement to fully stabilize employment. Thus, from the point of view of wage setters at an individual firm, indexation would only serve to further damp desired movements in the real wage.

6. Equilibrium when central banks do not cooperate

Here we will examine the Nash equilibrium which obtains when each central bank perceives that it cannot improve its own objective function through unilateral action. To focus on the game-theoretic aspects of the model, we will assume that central banks and private investors have full current-period information.[10] To further simplify, we will treat the home price of the domestically-produced good as the home central bank's control variable, though implicitly it is actually controlling the home money supply. This simplification can only be rigorously justified because both countries are assumed to experience identical goods market demand and productivity disturbances. (The analysis in appendix B allows for relative shifts in aggregate demand, and explicitly treats the money supplies as the control variables.)

Our solution algorithm is as follows: In the macro model of appendix A we solve for the effects of home and foreign money supply changes, holding base wage rates constant and assuming that CPI inflation rate and exchange rate depreciation expectations are static. In the analysis of the text, we employ the partial derivatives obtained in appendix A to solve for the time-consistent path of wages. We then confirm that static CPI inflation rate and exchange rate depreciation expectations are indeed rational (provided there are no regime changes).

Once base wage rates are set and the current-period disturbances are observed, the Nash first-order conditions for the two noncooperating central banks are[11]

$$(\partial\Lambda_t/\partial p_t)^{\mathrm{N}} = 2[\gamma-\tau\Psi][z_t/\alpha+\gamma(p_t-\bar{w}_t)-\tau q_t-(\tilde{n}-\bar{n})] + 2\chi(1+0.5\Psi)[p_t-p_{t-1}+0.5(q_t-q_{t-1})-\tilde{\pi}_I]=0, \tag{3a}$$

$$(\partial\Lambda_t^*/\partial p_t^*)^{\mathrm{N}} = 2(\gamma+\tau\Psi^*)[z_t/\alpha+\gamma(p_t^*-\bar{w}_t^*)+\tau q_t-(\tilde{n}^*-\bar{n}^*)] + 2\chi(1-0.5\Psi^*)[p_t^*-p_{t-1}^*-0.5(q_t-q_{t-1})-\tilde{\pi}_I^*]=0, \tag{3b}$$

where N superscripts stand for 'Nash' equilibrium, and $\Psi\equiv(\partial q/\partial dm)/(\partial p/\partial dm)>0$ [m is the home money supply, $dm\equiv m_t-v_t-E_{t-1}(m_t-v_t)$, v is the home money demand disturbance and E is the expectations operator]. Due to the symmetry of the underlying macroeconomic model of appendix A, $\Psi^*\equiv(\partial q/\partial dm^*)/(\partial p^*/\partial dm^*)=-\Psi$. One can also show that $(\gamma-\tau\Psi)>0$, i.e. an unanticipated increase in the home money supply raises home employment.

[10]The results here extend readily to the case of incomplete contemporaneous information [see Rogoff (1985)]. The operative assumption here is that all agents have the same information set.

[11]The second-order conditions for a local minimum are met; because of the quadratic forms of (1), the minimum is global.

Wage setters are assumed to correctly anticipate whether a cooperative or Nash regime will be in place in the ensuing period. By examining the first-order conditions (3), wage setters can choose base wage rates so that the expected real wage equals their target real wage. The underlying macro model is constructed so that wage setters' target (logarithm of the) real wage is zero, and so that $E_{t-1}(q_t)=0$. Taking $t-1$ expectations across (3), and setting expected real wages and the expected real exchange rate equal to zero yields:[12]

$$(\bar{w}_t)^{\mathrm{N}}=E_{t-1}(p_t)^{\mathrm{N}}=p_{t-1}+0.5q_{t-1}+\bar{\pi}_I^{\mathrm{N}}=(\bar{w}_t^*)^{\mathrm{N}}, \tag{4}$$

where $\bar{\pi}_I^{\mathrm{N}}\equiv\bar{\pi}_I+(\gamma-\tau\Psi)(\tilde{n}-\bar{n})/\chi(1+0.5\Psi)$.

By choosing base wage rates according to eqs. (4), wage setters assure themselves that the noncooperating central banks will, in the absence of disturbances, produce price levels consistent with wage setters' target real wage. Inspection of eqs. (4) reveals that nominal wage growth depends positively on $\tilde{n}-\bar{n}$, the difference between the central bank's and wage setters' target employment rate; wage growth is a decreasing function of the weight society places on stabilizing inflation versus stabilizing employment. Using the fact that $E_{t-1}(q_t)=0$, it is easy to deduce from (4) that the expected rate of change of the CPI, $E_t(p_{t+1}+0.5q_{t+1})-(p_t+0.5q_t)$, is constant and equal to $\bar{\pi}_I^{\mathrm{N}}$. Thus, as assumed in appendix A, rational CPI inflation rate expectations are indeed static.

Using eqs. (3) and (4), one can analyze the responses of the noncooperative system to unanticipated disturbances. Because the two countries are structurally identical, and because they experience identical goods market demand and aggregate supply (but not money demand) shocks, the real exchange rate q always turns out to be zero in Nash equilibrium, regardless of the realization of the disturbances.[13] Assuming that $q=0$ is indeed always a Nash equilibrium, one can solve (3) for p_t and p_{t-1}^* holding $q=0$. Then take $t-1$ expectations and subtract to form:

$$(p_t)^{\mathrm{N}}-E_{t-1}(p_t)^{\mathrm{N}}\equiv(\mathrm{d}p_t)^{\mathrm{N}}=-z_t/\alpha[\gamma+\chi(1+0.5\Psi)/(\gamma-\tau\Psi)]=(\mathrm{d}p_t^*)^{\mathrm{N}}. \tag{5}$$

Feasibility and uniqueness of the $q=0$ Nash equilibrium may be confirmed by using eqs. (26) of appendix A (together with their foreign counterparts) to substitute into eqs. (3) for q, p and p^* in terms of m, m^*, $\bar{w}$, $\bar{w}^*$, $\bar{\pi}$, $\bar{\pi}^*$ and the disturbances (setting $x=0$).

To compare social welfare under the Nash regime with social welfare under a cooperative regime, it will be necessary to compute $E_{t-1}(\Lambda_t)^{\mathrm{N}}$. Using

[12]Here is the first of many times where we make use of the fact that certainty equivalence obtains because the objective functions are quadratic; see Sargent (1979).

[13]With relative shifts in demand between home and foreign goods, as in appendix B, the real exchange rate does fluctuate in both the Nash and the cooperative regimes.

the fact that $q^{\mathrm{N}}=0$, it is possible to decompose the social loss function into three components:

$$E_{t-1}(\Lambda_t)^{\mathrm{N}}=(\tilde{n}-\bar{n})^2+\chi\Pi^{\mathrm{N}}+\Gamma^{\mathrm{N}}, \tag{6}$$

where

$$\Pi^{\mathrm{N}}\equiv[(\bar{\pi}_I)^{\mathrm{N}}-\tilde{\pi}_I]^2, \Gamma^{\mathrm{N}}\equiv E_{t-1}\{[z_t/\alpha+\gamma(\mathrm{d}p_t)^{\mathrm{N}}]^2+\chi[(\mathrm{d}p_t)^{\mathrm{N}}]^2\}.$$

The first element of $E_{t-1}(\Lambda_t)^{\mathrm{N}}$ is nonstochastic; because monetary policy cannot systematically raise the employment rate, $\tilde{n}-\bar{n}$ can be reduced only by directly addressing the underlying cause of the real distortion. (This issue is beyond the scope of the present paper.) The second term, $\chi\Pi^{\mathrm{N}}$, measures the extent to which the expected CPI inflation rate exceeds society's target rate. This second term is also independent of current-period disturbances but, as discussed in section 5, it is a function of the policy regime. The final term, Γ^{N}, measures the extent to which the central bank succeeds in stabilizing (a weighted average of) the employment rate and the CPI inflation rate around their expected *market-determined* values. Note that although the central banks actually attempt to stabilize inflation and employment around their socially-preferred values, in a time-consistent equilibrium the central banks appear to respond to disturbances as if they were trying to stabilize inflation and employment around their mean market-determined values. (This result is due to the quadratic form of the objective functions.) To evaluate Γ^{N}, substitute in for $(\mathrm{d}p_t)^{\mathrm{N}}$ using eq. (5):

$$\Gamma^{\mathrm{N}}=(\sigma_z^2/\alpha^2)[(\chi')^2+\gamma^2\chi]/(\gamma^2+\chi')^2=(\Gamma^*)^{\mathrm{N}}, \tag{7}$$

where σ_z^2 is the variance of the zero mean supply shock, $E_{t-1}(z_t^2)$, and $\chi'\equiv\gamma\chi(1+0.5\Psi)/(\gamma-\tau\Psi)$.

Note that money demand shocks do not appear in eq. (7) since, to the extent the shocks are known (here information is perfect), they can be completely neutralized through temporary money supply infusions. Complete offset of money demand disturbances is optimal since they present no trade-off between price-level stability and employment stability. Thus, the home central bank will react to home money demand disturbances in the same fashion whether or not it takes the utility function of the foreign central bank into account.[14]

Goods market demand shocks do not disturb the Nash equilibrium only because we have made the simplifying assumption that both countries

[14]Henderson (1984) derives a similar result. If the central banks place weight on achieving their money supply targets, as in Canzoneri and Gray (1985), then the cooperative and noncooperative response to money demand shocks will no longer be equivalent.

experience the same goods market demand disturbance. (This assumption is relaxed in appendix B.) Provided that both countries alter their money supplies equally to offset the mutual disturbance, there will be no effect on home and foreign prices and employment. The level of world real interest rates will move to offset the disturbance, but the real exchange rate will remain fixed. The resulting equilibrium is Nash because neither side has any incentive to unilaterally alter its money supply.

On the other hand, aggregate supply disturbances do affect the price levels which arise in Nash equilibrium in spite of our simplifying assumption that the home and foreign supply shocks are perfectly correlated. Because an aggregate supply shock alters the full-information real wage, it creates a trade-off between price level stability and employment stability. In the next section we demonstrate that, ignoring systematic effects on the inflation rate, the cooperative response to supply shocks is superior to the noncooperative response.

7. Equilibrium when central banks cooperate to achieve their stabilization objectives

Examining the first-order conditions for the Nash equilibrium [eqs. (3)], we see that the incentives of the central banks to unilaterally inflate are reduced by their fears of the concomitant effects on the real exchange rate. In this section we will assume that the two central banks engage in a binding cooperative agreement, under which they choose the symmetric point on their contract curve (given the base wage rates they face).[15] Equivalently, they could agree to fix their nominal exchange rate and allow either symmetric country to lead in choosing price levels. We will demonstrate below that such an agreement is mutually beneficial only if the variance of supply shocks is large relative to distortions in the labor markets.

Under the cooperative fixed real exchange rate ($q=0$) regime, the first-order condition for minimization of the home social welfare function is given by:

$$\gamma[z_t/\alpha+\gamma(p_t-\bar{w}_t)-(\tilde{n}-\bar{n})]+\chi(p_t-p_{t-1}-\tilde{\pi}_I)=0. \tag{8}$$

(The corresponding foreign-country equation is identical.)

In deriving eq. (8), we have made use of the fact that $\partial q/\partial dm$ is zero in the cooperative equilibrium, since each central bank can count on the other to

[15] There are other, asymmetric, cooperative schemes which, holding wages constant, lead to Pareto improvements over the Nash equilibrium. Qualitatively, all of these schemes are similar in that they involve higher money growth at home and abroad than in the Nash equilibrium. The symmetric scheme analyzed in the text is a logical one to consider since the two countries are identical in almost every respect. Canzoneri and Gray (1985) have emphasized that fixed exchange rate regimes may be noncooperative in that either country can unilaterally precommit to fix the exchange rate.

match any marginal change in its money supply. Eqs. (9), (10), and (11) are derived using the same algorithm used to derive eqs. (4), (5), and (7) of the previous section; 'C' superscripts stand for 'cooperative regime':

$$(\bar{w}_t)^{\mathrm{C}} = E_{t-1}(p_t)^{\mathrm{C}} = p_{t-1} + (\bar{\pi}_I)^{\mathrm{C}} = (\bar{w}_t^*)^{\mathrm{C}}, \tag{9}$$

$$(p_t)^{\mathrm{C}} - E_{t-1}(p_t)^{\mathrm{C}} \equiv (\mathrm{d}p_t)^{\mathrm{C}} = (\mathrm{d}p_t^*)^{\mathrm{C}} = -z_t/\alpha(\gamma+\chi/\gamma), \tag{10}$$

$$\Gamma^{\mathrm{C}} = (\sigma_z^2/\alpha^2)[\chi/(\gamma^2+\chi)] = (\Gamma^*)^{\mathrm{C}}, \tag{11}$$

where $(\bar{\pi}_I)^{\mathrm{C}} \equiv \tilde{\pi}_I + \gamma(\tilde{n}-\bar{n})/\chi$. Comparison of eqs. (9) and (4) reveals that the mean rate of CPI inflation is indeed higher under the cooperative regime than under the noncooperative regime. The intuitive explanation is exactly as discussed in section 5: wage setters anticipate that the two central banks will have stronger incentives to inflate in a regime where each can count on the other's cooperation, so that the benefits of inflation are not reduced by real exchange rate depreciation.

A comparison of eqs. (10) and (5) reveals that $|(\mathrm{d}p_t)^{\mathrm{C}}| > |(\mathrm{d}p_t)^{\mathrm{N}}|$. In the Nash equilibrium, the central banks allow the supply shock to affect employment more, and inflation less, than in the cooperative equilibrium.[16] It is easy to prove that the cooperative response to disturbances is superior, i.e. $\Gamma^{\mathrm{C}} < \Gamma^{\mathrm{N}}$:

Proof. Note that expressions (11) and (7) can be written in the same general form since $\chi/(\gamma^2+\chi) = (\chi^2+\gamma^2\chi)/(\gamma^2+\chi)^2$. Differentiating the expression $(y^2+\gamma^2\chi)/(\gamma^2+y)^2$ with respect to y yields $2\gamma^2(y-\chi)/(\gamma^2+y)^{-3}$. Note that this derivative is strictly positive for $y>\chi$ (since $\chi>0$), and note that $\chi'>\chi$. Q.E.D.

It is easy to generalize the foregoing analysis to the case where the two countries are identical except for their labor market distortions. One can then demonstrate that the country with the smaller labor market distortion may prefer the cooperative regime, while the other country would be better off under a noncooperative regime. (If a country had no labor market distortion, it would not have to worry about aggravating its inflation distortion, and thus would always prefer the cooperative regime regardless of the variance of the disturbances.)

While the result that a cooperative regime may produce higher expected inflation rates arises in a sensible way, it is not general. Suppose we alter the

[16] Canzoneri and Gray (1985) analyze a one-time supply disturbance and find that the cooperative response to this disturbance may call for either smaller or larger changes in the money supply than in the Nash equilibrium. In their framework, the authorities try to stabilize employment and money growth. The present framework may also yield the result that $|\mathrm{d}p_t|^{\mathrm{C}} < |\mathrm{d}p_t^{\mathrm{N}}|$ when the central banks adopt the money supply as an intermediate monetary target, along the lines discussed in Rogoff (1985).

central banks' objective functions to depend on employment and money supply growth (instead of employment and inflation); this type of monetary targeting objective function is used by Canzoneri and Gray (1985). When employment/monetary targeting objective functions are combined with the macro model of appendix A, the cooperative regime turns out to have a lower time-consistent inflation rate if, holding base wage rates constant, foreign money supply growth lowers domestic employment.[17] This will be the case provided the expenditure-switching effect of the real foreign currency depreciation (induced by an unanticipated foreign money supply increase) outweighs the expenditure-increasing effect of lower world real interest rates (assuming there is no wage indexation.) If instead the expenditure-increasing effects dominate, then the cooperative regime will be more inflationary. This ambiguity did not arise with the employment-inflation objective functions used in our earlier analysis, since joint money supply growth always produces a better employment/inflation trade-off than unilateral money growth.

8. Institutional designs for superior cooperative regimes

The possibility that the regime we have labeled 'cooperative' might be inferior to the 'non-cooperative' regime does not violate the basic tenets of game theory: the central banks are assumed to cooperate with each other, but not with private sector wage setters. Of course, if the central banks were able credibly to guarantee that they would not systematically try to raise employment, and would only use monetary policy to offset disturbances, then it would be possible to achieve a superior and truly cooperative outcome. (A still better cooperative equilibrium could be obtained if the two countries could eliminate their labor market distortions at low cost.) The present analysis does suggest cases in which government to government cooperation might lead to better institutional reforms. Suppose, for example, each country passed a binding law fixing the future path of its money supply except for prespecified responses to specific disturbances.[18] If the two countries design their monetary constitutions independently, the prespecified response to common supply disturbances might be Nash, whereas if they design their systems jointly, the prespecified response might be closer to the cooperative one.[19] The behavior of governments in other countries will, in general, be a

[17]Oudiz and Sachs (1985) provide an example in which cooperation between central banks eliminates their credibility problems with the private sector.

[18]Buiter (1981) specifies optimal contingent rules. There are, of course, many problems involved in designing an institutional framework in which to implement such rules. Rogoff (1985) and Canzoneri (1985) discuss institutional responses to the central bank's time-consistency problem in a closed economy context.

[19]McKinnon (1982) suggests a cooperative monetary reform. His specific proposal to fix the path of the world money supply would definitely be an improvement over money-supply targeting by individual countries in a world where the main source of disturbances is currency substitution.

consideration in evaluating any institutional response to the time-consistency problem discussed here. Thus, it should be clear that an optimally-designed cooperative regime is superior to any noncooperative scheme.

9. Conclusions

A regime in which governments conduct monetary policy independently may produce lower time-consistent inflation rates than a regime in which central banks cooperate; inter-governmental cooperation can exacerbate the central banks' credibility problems vis-à-vis the private sector. While the conditions under which cooperation leads to systematically higher inflation rates are quite plausible, we have also indicated an example where cooperation ameliorates the central banks' credibility problems. In either event, the cooperative response to unanticipated disturbances is always at least as good as the noncooperative response, in the sense of stabilizing employment and inflation around their mean market-determined values.

While the main result has been expressed in a rational expectations cum wage contracting model, it clearly can arise in models with alternative nonneutralities and different sources of time-consistency problems. Cooperation can be counterproductive, for example, in a flexible-price currency-substitution model, in which each central bank is trying to maximize seignorage. The key point is that it can be misleading to model the strategic interactions of two governments without also modeling the game between the governments and the private sector.

Appendix A: The underlying two-country macroeconomic model

Here we describe the two-country, two-good, rational expectations cum wage contracting model on which the results of the text are explicitly based. Unanticipated monetary policy can have real effects here because nominal wage contracts are negotiated a period in advance; these contracts are only partially indexed to the current-period consumer price level.[20] To facilitate algebraic manipulation, the technological and behavioral parameters in the two countries are constrained to be equal. Indeed, we will refer only to domestic variables and equations where discussion of their foreign counterparts is redundant.

A.1. Aggregate supply

The good produced by home-country firms differs from the good produced by foreign-country firms. But within each country, all firms have identical

[20]As Gray (1976) demonstrates, full price-level indexation is suboptimal in the presence of supply (productivity) shocks. Apart from its game-theoretic aspects, the model is quite similar to ones employed by Daniel (1981), Henderson and Waldo (1983), and Canzoneri and Gray (1985).

Cobb–Douglas production functions. Using lower case letters to denote logarithms, the aggregate production function can be written as

$$y=c_0+\alpha\bar{k}+(1-\alpha)n+z, \tag{12}$$

where y is output, $\bar{k}$ is the fixed capital stock, n is labor, c_0 is the constant term, and z is a serially uncorrelated aggregate productivity disturbance; $z \sim N(0,\sigma_z^2)$. The foreign country shares the same productivity disturbance, so that $z^*=z$. [Star (*) superscripts denote foreign-country variables.] Time subscripts are omitted where the meaning is obvious; throughout, all parameters are non-negative.

Firms hire labor until the marginal value product of labor equals the nominal wage rate, w:

$$c_0+\log(1-\alpha)+\alpha\bar{k}-\alpha n_{\mathrm{d}}+z=w-p, \tag{13}$$

where p is the nominal price of the domestically-produced good, and n_{d} is aggregate labor demand. The notional labor supply curve is assumed inelastic (the results are not qualitatively affected when labor supply depends positively on the real wage):

$$n_{\mathrm{s}}=\bar{n}. \tag{14}$$

To simplify algebra, $\bar{n}$ is set equal to $\bar{k}+(1/\alpha)[\log(1-\alpha)+c_0]$, $\bar{n}=\bar{n}^*$ and $\bar{k}=\bar{k}^*$.

CPI-indexed wage contracts for period t are negotiated at the end of period $t-1$. The base wage rate is $\bar{w}$ and the indexation parameter is β:

$$w=\bar{w}+\beta(p_I-\bar{w}), \quad 0 \leqq \beta < 1, \tag{15}$$

$$p_I=0.5p+0.5(p^*+e), \tag{16}$$

where e is the (logarithm of the) exchange rate (the domestic currency price of foreign currency). The nature of the employment contract is that laborers agree to supply (ex post) whatever amount of labor is demanded by firms in period t, provided firms pay the negotiated wage. The actual levels of employment in period t are thus found by substituting the wage equation (15) into the labor demand equation (13):

$$n=\bar{n}+\gamma(p-\bar{w})-\tau q+z/\alpha, \tag{17a}$$

$$n^*=\bar{n}+\gamma(p^*-\bar{w}^*)+\tau q+z/\alpha, \tag{17b}$$

where $\gamma \equiv (1-\beta)/\alpha$, $\tau \equiv 0.5\beta/\alpha$, and

$$q=e+p^*-p. \tag{18}$$

(Note that q always appears with the opposite sign in the otherwise identical foreign-country equations.) As described in the text, wage setters choose $\bar{w}$ to minimize $E_{t-1}(n_t-\bar{n})^2$; thus $\bar{w}=E_{t-1}[p_t-0.5\beta q_t/(1-\beta)]$. The indexation parameter, β, is taken as given; see footnote 9 above.

Eqs. (12) and (17), together with the assumption that $-c_0=\alpha\bar{k}+(1-\alpha)\bar{n}$, imply that the aggregate supply equation can be written as

$$y_s=\theta(p-\bar{w})-\kappa q+z/\alpha, \tag{19}$$

where $\theta\equiv(1-\alpha)(1-\beta)/\alpha$ and $\kappa\equiv 0.5(1-\alpha)\beta/\alpha$.

A.2. Money and bond markets

Only domestic residents hold the domestic money and only foreign residents hold the foreign money. However, residents of both countries hold both domestic- and foreign-currency denominated bonds. The demand for real money balances in each country is a decreasing function of the nominal interest rate and an increasing function of real income:

$$m-p_I=-\lambda r+\phi(p+y-p_I)+v, \tag{20}$$

where m is the logarithm of the nominal money supply and v is the money market disturbance terms; $v\sim N(0,\sigma_v^2)$, and v and v^* are independent.

Domestic- and foreign-currency denominated bonds are perfect substitutes so that uncovered interest parity holds:[21]

$$E_t(e_{t+1})-e_t=r_t-r_t^*. \tag{21}$$

Private agents are assumed to have full knowledge of the period t disturbances in making their portfolio and investment decisions.

A.3. Goods market demand

Demand for the good produced in each country is a decreasing function of its relative price, an increasing function of real income at home and abroad, and a decreasing function of the real interest rate:

$$\begin{aligned} y_d=\eta q-\delta(1-2\Delta)\{r-E_t[p_{I(t+1)}]+p_{It}\}+\Delta(p+y-p_I)\\ +\Delta(p^*+y^*-p_I^*)+u(1-2\Delta)+x, \end{aligned} \tag{22}$$

[21]There seems little harm in abstracting from the macroeconomic effects of sterilized intervention, since those effects appear to be extremely limited. See, for example, Rogoff (1984).

where $u \sim N(0, \sigma_u^2)$, $x \sim N(0, \sigma_x^2)$ and $\Delta < 0.5$. u is a common goods market demand disturbance and x represents a shift in demand from the foreign good to the home good. (u and δ are multiplied by $1-2\Delta$ as a convenient normalization.)

A.4. Solution of the model

To close the model, it is necessary to specify how wage setters and investors form expectations of future prices. The solution algorithm employed here involves first assuming and then proving that rational expectations are equivalent to static expectations for the rate of change of the exchange rate and for the home and foreign CPI inflation rates. [Note that eqs. (16) and (21) imply that $E_t(e_{t+1}) - e_t = \bar{\pi}_I - \bar{\pi}_I^*$.] By imposing the 'static expectations are rational' assumption, we can solve the model of eqs. (17)–(22) for q, p, p^*, p_I, p_I^*, n, and n^* as functions of $\bar{w}$, $\bar{w}^*$, $\bar{\pi}_I$, $\bar{\pi}_I^*$, z, u, x, v, and v^*. Then, in the text, we use the resulting partial derivatives [see eqs. (26) below] to solve for the time-consistent values of $\bar{w}$, $\bar{w}^*$, $\bar{\pi}_I$, $\bar{\pi}_I^*$, and $E_t(e_{t+1}) - e_t$. (These values depend, of course, on whether the central banks are engaged in a cooperative or noncooperative regime.) The analysis of the text confirms that time-consistent expectations for exchange rate depreciation and CPI inflation rates are indeed static (in the absence of regime shifts).

Taking $t-1$ expectations across eqs. (19) and (22) (together with their foreign counterparts) and recalling that wage setters set $\bar{w} = E_{t-1}[p_t - 0.5\beta q_t/(1-\beta)]$, one can solve for

$$E_{t-1}(q_t) = 0 = \bar{w} - E_{t-1}(p_t), \tag{23}$$

$$E_{t-1}(r - \bar{\pi}_I) = E_{t-1}(y_t) = 0, \tag{24}$$

$$E_{t-1}(m_t) = \bar{w} - \lambda \bar{\pi}_I. \tag{25}$$

Given our expectational assumptions, the solutions for q, p, p_I, and n are (solutions for p^*, p_I^* and n^* are symmetric):

$$q = v[(m - \bar{w} + \lambda \bar{\pi}_I - v) - (m^* - \bar{w}^* + \lambda \bar{\pi}_I^* - v^*) - 2(\phi + 1/\theta)x], \tag{26a}$$

$$\begin{aligned} p = \bar{w} &+ (vS + H)(m - \bar{w} + \lambda \bar{\pi}_I - v) - vS(m^* - w^* + \lambda \bar{\pi}_I^* - v^*) \\ &+ \lambda H u/\delta - H(\phi + \lambda/\delta) z/\alpha + [\lambda H/\delta - 2vS(\phi + 1/\theta)]x, \end{aligned} \tag{26b}$$

$$\begin{aligned} p_I = \bar{w} &+ (vJ + H)(m - \bar{w} + \lambda \bar{\pi}_I - v) - vJ(m^* - \bar{w}^* + \lambda \bar{\pi}_I^* - v^*) \\ &+ \lambda H u/\delta - H(\phi + \lambda/\delta) z/\alpha + [H\lambda/\delta - 2vJ(\phi + 1/\theta)]x, \end{aligned} \tag{26c}$$

$$n=\bar{n}+(Q+Rv)(m-\bar{w}+\lambda\bar{\pi}_I-v)-Rv(m^*-\bar{w}^*+\lambda\bar{\pi}_I^*-v^*)$$
$$+Q\lambda u/\delta+Q[-\phi-\lambda/\delta+1/(1-\beta)]z+[Q\lambda/\delta-2Rv(\phi+1/\theta)]x, \tag{26d}$$

where

$$v\equiv[2(\eta+\kappa)/\theta+2\phi\eta+(1-\phi)]^{-1}>0, H\equiv(1+\theta\lambda/\delta+\phi\theta)^{-1}>0,$$

$$S\equiv H[\kappa\phi-(1-\phi)/2+\lambda(\kappa+\eta)/\delta]\gtreqless 0,$$

$$J\equiv H\{0.5\phi[(1-\alpha)/\alpha+1]+\lambda/\delta[0.5(1-\alpha)/\alpha+\eta]\}>0,$$

$$Q\equiv[\phi(1-\alpha)+\lambda(1+\alpha)/\delta+\alpha/(1-\beta)]^{-1}>0,$$

$$R\equiv Q\{0.5[\phi-1/(1-\beta)]+\lambda\eta/\delta\}\gtreqless 0.$$

Using eqs. (26), and imposing the assumption that the income elasticity of money demand $\phi\leqq 1$, one can determine the sign of the following partial derivatives (holding $\bar{w}$, $\bar{w}^*$, $\bar{\pi}_I$, and $\bar{\pi}_I^*$ constant):

$$\partial q/\partial m,\quad \partial p/\partial m,\quad \partial p_I/\partial m,\quad \partial n/\partial m,\quad \partial p/\partial u,\quad \partial p_I/\partial u,\quad \partial n/\partial u>0;$$

$$\partial n/\partial x\gtreqless 0;$$

$$\partial p_I/\partial x,\quad \partial q/\partial x,\quad \partial p_I/\partial m^*,\quad \partial p_I/\partial z,\quad \partial p/\partial z<0.$$

The partial derivatives $\partial p/\partial x$, $\partial p/\partial m^*$, $\partial n/\partial m^*$, and $\partial n/\partial z$, may be positive or negative. For example, when there is no wage indexation a foreign money supply shock will raise or lower domestic output and employment, depending on whether the expenditure-switching effect of the real appreciation of the domestic currency outweighs the expenditure-increasing effect of lower world real interest rates.[22] Wage indexation increases the possibility that the foreign money supply shock will raise domestic employment.

In the text, we require knowledge of $\Psi\equiv(\partial q/\partial m)/(\partial p/\partial m)$, holding m^*, $\bar{w}$, $\bar{w}^*$, $\bar{\pi}_I^*$, and $\bar{\pi}_I^*$ constant. One can easily demonstrate, using (26), that $\Psi>0$.

Appendix B: Relative shifts in demand

Throughout the text, shifts in the demand for each country's good are assumed to be perfectly positively correlated. This assumption is analytically

[22]Daniel (1981) discusses these transmission channels, as do Canzoneri and Gray (1985). If $\beta=0$, so that there is no wage indexation, and if the income elasticity of money demand, ϕ, equals one, then $\partial p/\partial m^*$, $\partial n/\partial m^*<0$. If $\beta>0$, then $\partial n/\partial m^*$ may be positive even if $\phi=1$.

convenient because it turns out to imply that the real exchange rate q does not move in either the Nash or the symmetric cooperative equilibrium. To solve the model when there are relative shifts in the demand for the two goods (denoted by x), use eqs. (26) to substitute into eqs. (1) for $n-\bar{n}$ and π_t:

$$\Lambda=(a_1dm+a_2dm^*+a_3x+\bar{n}-\tilde{n})^2$$

$$+\chi(b_1dm+b_2dm^*+b_3x+\bar{w}-p_{t-1}-\tilde{\pi})^2, \tag{27}$$

where $dm\equiv m-\bar{w}+\lambda\bar{\pi}-v$, $dm^*\equiv m^*-\bar{w}^*+\lambda\pi_I^*-v^*$, and the coefficients a_i and b_i are the same as in (26). (As a minor expositional convenience, we are abstracting from the common disturbances u and z. Again, the equation for Λ^* is symmetric, except that x enters with opposite sign.) In the Nash equilibrium, $\partial\Lambda/\partial dm=0=\partial\Lambda^*/\partial dm^*$. The procedure for finding $\bar{w}^{\mathrm{N}}$ and $(\bar{w}^*)^{\mathrm{N}}$ is the same as in the text, and the resulting equations are the same as eqs. (4). Together, eqs. (4) and (27) (with its foreign counterpart) imply

$$dm^{\mathrm{N}}=-(a_1a_3+\chi b_1b_3)x/[a_1(a_1-a_2)+\chi b_1(b_1-b_2)]=-(dm^*)^{\mathrm{N}}, \tag{28}$$

where from eqs. (26), $a_1(a_1-a_2)+\chi b_1(b_1-b_3)>0$, but $a_1a_3+\chi b_1b_3 \gtreqless 0$. A positive x represents a shift in world demand from the foreign good to the home good; home CPI inflation falls and home employment rises. In the Nash equilibrium, the home country may respond to unanticipated relative demand shifts with either positive or negative unanticipated money growth, depending (in part) on χ, the relative weight placed on inflation deviations versus employment deviations.

Provided that the responses to relative demand shifts are symmetric, the cooperative $\bar{w}^{\mathrm{C}}$ and $(\bar{w}^*)^{\mathrm{C}}$ are as in the text [eqs. (9)], and

$$dm^{\mathrm{C}}=-[(a_1-a_2)a_3+\chi(b_1-b_2)b_3]x/[(a_1-a_2)^2+\chi(b_1-b_2)^2]$$

$$=-(dm^*)^{\mathrm{C}}. \tag{29}$$

Since $b_2<0$ and $a_2\gtreqless 0$, it is perfectly possible that dm^{C} and dm^{N} are actually of opposite signs.

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