International monetary cooperation in a world of imperfect information*

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Abstract

This paper examines the welfare implications of international monetary cooperation using a stylised two-country New Keynesian general equilibrium model of imperfect information. We show that setting a self-oriented monetary policy rule generally leads to welfare gains relative to passive monetary policy even when central banks do not have perfect information about the foreign economy. However, information sharing between central banks in this set-up, by itself, has ambiguous welfare implications. Gains from monetary coordination are largest when productivity shocks are negatively correlated across countries.

Keywords: policy coordination, imperfect information, monetary policy, new open economy macroeconomics.

JEL Classification: F41; F42.

1 Introduction

This paper examines the role of information sharing between central banks in a two-country open economy general equilibrium model of the kind developed by Obstfeld and Rogoff (2000a, 2002, hereafter OR). The key difference in our analysis is that central banks have imperfect information: they cannot observe productivity shocks abroad.[1] Introducing imperfect information in this way allows us to separate the welfare gains from two different types of international monetary cooperation

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[1] Our focus is therefore different from Dellas (2005), who evaluates alternative monetary policy rules when central banks observe domestic shocks only with a time lag.

– gains from information sharing between central banks, and gains from implementing coordinated monetary policy under perfect information. Our results show that in this stylised set-up, information sharing between central banks, by itself, has generally ambiguous welfare implications. On the one hand, better information allows policy makers to respond appropriately to common shocks. But on the other hand, because the better information allows policy makers to respond to a wider set of shocks, this can generate spillover effects which are not necessarily internalised. We also find that setting a self-oriented monetary policy rule generates large welfare gains relative to following passive monetary policy, even when monetary authorities do not have full information about the state of the world economy. Gains from international monetary coordination under perfect information are found to be greatest when productivity shocks are negatively correlated across countries.

This paper contributes to the growing literature which explores the welfare implications of international monetary policy cooperation in the 'second generation' macroeconomic model.[2] Using a stylised two-country general equilibrium model consisting of optimising households, monopolistic competition and nominal rigidities, OR (2000a and 2002) have shown that the welfare gains from international monetary coordination are small compared to the gains achieved from countries setting self-oriented monetary policy rules. However, the quantitative estimates of gains from international monetary policy coordination are sensitive to the way various economic frictions – such as financial market structure, nominal rigidity, and exchange rate pass-through – are modelled. Clearly, international monetary coordination is irrelevant in a world of complete financial markets since the availability of state-contingent assets eliminates any need for international risk-sharing through monetary policy. Sutherland (2004) shows that the gains from international monetary coordination could be larger under incomplete financial markets than under financial autarky – which is assumed in OR's analysis – when the elasticity of substitution between Home and Foreign goods are greater than unity. Benigno (2001) also demonstrates that the gains from international monetary coordination are larger when financial markets are incomplete and the initial holdings of foreign assets are asymmetric across countries. Canzoneri *et al.* (2005) show that when different sectors of the domestic economy are subject to heterogeneous productivity shocks, monetary policy cannot replicate the flexible-wage outcome and gains from international monetary coordination are larger than those postulated by OR. Finally, gains from international monetary coordination could also depend non-linearly on firms' pricing behaviour and the degree of exchange rate pass-through (Corsetti and Pesenti, 2005). Our analysis focuses on the role of informational frictions, which has not yet been examined in this literature.

This paper is also related to the 'first generation' literature which examines the welfare implications of uncertainty and learning in international monetary cooperation. The 'first generation' models of international monetary cooperation – represented by *inter alia* Oudiz and Sachs (1985) – tend to rely on *ad hoc* assumptions about policy makers' objectives, which typically incorporate an output-inflation trade-off. Using such a model, Ghosh and Masson (1991) examine the welfare implications of international monetary coordination when central banks face uncertainty about the

[2] See, for example, Lane (2001) for an overview of the 'second generation' research agenda.

'true' transmission mechanism of monetary policy and other shocks. They show that activist policies (either Nash or coordinated) produce large welfare gains relative to passive policies if central banks learn about the 'true' monetary transmission mechanism from observed variables, but they yield large losses in the absence of learning by central banks. Our analysis confirms in a 'second generation' model that activist monetary policies (Nash or coordinated) dominate passive policies when central banks update their beliefs about foreign productivity shocks after observing domestic shocks. In addition, we examine the impact of information sharing amongst central banks, an issue not explored by Ghosh and Masson.

The rest of the paper is organised as follows. Section 2 presents the structure of a canonical variant of OR's two-country general equilibrium model. We extend this model in Section 3 by introducing imperfect information, and examine the welfare implications by varying the information sets about foreign productivity shocks available to domestic policy makers. We also consider how the degree of correlation between domestic and foreign productivity shocks affects the welfare gains from international monetary cooperation. Section 4 discusses the implications of our results and concludes.

2 Monetary policy interdependence under perfect information

This section outlines the key features of the OR model which we extend in the next section to incorporate imperfect information. The details of the model and the derivation of each equation can be found in OR (2000a, 2000b, 2002). Here, we only highlight the key assumptions behind the economic frictions, the interlinkages between the two economies, and monetary policy in this model. Those familiar with this model can skip the following and proceed to sub-section 2.3.

2.1 Obstfeld and Rogoff model: set-up

OR (2000a, 2002) use a static general equilibrium model which comprise two symmetric and equally-sized open economies, to examine the welfare gains from international monetary cooperation. All agents are assumed to have perfect information about all parameters of the model. The model consists of a two-stage game. In the first stage, agents set wages to maximise their expected utility, and central banks set their monetary policy rules which specify their responses to unexpected domestic and foreign productivity shocks. In the second stage, upon observing the productivity shocks realised in the two countries, each central bank adjusts money supply according to the pre-set rule, and agents in both countries choose their consumption and labour supply given the pre-set wage. OR assume that central banks can commit to a monetary policy rule and thereby abstract from the possibility of any time-inconsistency problem.

Home agents produce two types of goods – tradable (indexed by T) and non-tradable (indexed by N) – and consume three kinds of goods: non-tradables produced at Home (indexed by N), tradables produced at Home (indexed by H) and Foreign-produced imported tradables (indexed by F). The overall real consumption index C for a Home agent is given by $C = \frac{C_T^{\gamma} C_N^{1-\gamma}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}$, where γ

captures the degree of the economy's openness to trade, and $C_T = 2C_H^{1/2}C_F^{1/2}$. Foreign preferences are specified in an identical way. In what follows, all Foreign variables are indicated with asterisks (*).

Product and labour markets are characterised by monopolistic competition: firms produce differentiated products using differentiated labour, which is the only input for production. Elasticities of substitution in consumer preference and production function are assumed to be constant. The representative Home agent i's utility U^i is a function of consumption C^i, real money balances $\frac{M^i}{P}$, and labour disutility $\frac{K}{\nu}(L^i)^\nu$:

$$U^i = \frac{(C^i)^{1-\rho}}{1-\rho} + \chi \log \frac{M^i}{P} - \frac{K}{\nu}(L^i)^\nu \tag{1}$$

where $\rho > 0$ is the constant coefficient of relative risk aversion, L^i is the total individual labour supply to both sectors of production, and $v \geq 1$. The marginal disutility of labour, K, is stochastic, and a high K can be interpreted as a negative country-wide Home productivity shock. The Foreign productivity shock, K^*, is distributed symmetrically, though not necessarily independently. As we will show later, ρ, v and the degree of correlation between K and K^* are critical determinants of welfare gains from international monetary policy coordination and information sharing.

In this model, only nominal wages are assumed to be pre-set. The optimal nominal pre-set wage equalises the expected marginal revenue (in consumption units) and the expected marginal disutility from the additional hours worked:

$$W(i) = \left(\frac{\phi}{\phi-1}\right)\frac{E\{K(L^i)^\nu\}}{E\{\frac{L^i(C^i)^{-\rho}}{P}\}}$$

where P is the domestic-currency price index for C_H, C_F, and C_N ($P = P_T^\gamma P_N^{1-\gamma}$ and $P_T = P_H^{1/2}P_F^{1/2}$). The mark-up over the expected marginal disutility of labour, $\frac{\phi}{\phi-1}$, reflects the monopolistic competition in the labour market, where ϕ is the elasticity of substitution between differentiated labour in the production functions. Since the monopolistic firms facing constant and identical elasticities of demand at home and abroad optimally set price mark-ups over marginal cost, and labour is the only input, the domestic-currency product prices are set equal to constant mark-ups over the fixed nominal wage:

$$\begin{aligned} P_N &= P_H = \left(\frac{\theta}{\theta-1}\right)W,\ P_N^* = P_F^* = \left(\frac{\theta}{\theta-1}\right)W^* \\ P_H^* &= \frac{1}{\varepsilon}\left(\frac{\theta}{\theta-1}\right)W = \frac{1}{\varepsilon}P_H,\ P_F = \varepsilon\left(\frac{\theta}{\theta-1}\right)W^* = \varepsilon P_F^* \end{aligned} \tag{2}$$

The real exchange rate and the terms of trade are therefore functions of the nominal exchange rate and the ratio of the nominal pre-set wages in the two countries, so that:

$$\text{Real exchange rate} \quad : \quad \frac{\varepsilon P^*}{P} = \frac{\varepsilon P_T^{*\gamma} P_N^{*1-\gamma}}{P_T^{\gamma} P_N^{1-\gamma}} = \left(\frac{\varepsilon W^*}{W}\right)^{1-\gamma}$$

$$\text{Terms of trade} \quad : \quad \frac{\varepsilon P_F^*}{P_H} = \frac{\varepsilon W^*}{W}$$

In each country, the market for non-tradables clears when $C_N = Y_N$ and $C_N^* = Y_N^*$, and the market for tradables clear when consumption is equalised across the two countries, $C_T = C_T^*$. This, together with the Cobb-Douglas consumption preferences, implies that Home and Foreign spending measured in units of tradables, defined as Z and Z^*, is always equal, where:

$$Z \equiv C_T + \left(\frac{P_N}{P_T}\right) C_N = Z^*$$

The model is solved by assuming that the monetary and productivity shocks $\{m, m^*, \kappa, \kappa^*\}$ are jointly normally distributed, where lower case letters denote natural logs (e.g. $\kappa = \log K$ and $m = \log M$). The Home and Foreign log productivity shocks are assumed to have identical means and variances, such that $E\kappa = E\kappa^*$ and $\sigma_\kappa^2 = \sigma_{\kappa^*}^2$. Further, 'difference' and 'world' productivity shocks, κ_d and κ_w, are defined as:

$$\kappa_d = \frac{\kappa - \kappa^*}{2},\ \kappa_w = \frac{\kappa + \kappa^*}{2}$$

The Home and Foreign monetary policy rules are linear reaction functions to unanticipated 'world' and 'difference' shocks:

$$\widehat{m} = -\delta_d \widehat{\kappa}_d - \delta_w \widehat{\kappa}_w \tag{3}$$

$$\widehat{m}^* = \delta_d^* \widehat{\kappa}_d - \delta_w^* \widehat{\kappa}_w \tag{4}$$

where carets over variables denote the surprise components, e.g. $\widehat{m} = m - Em$ and $\widehat{\kappa}_d = \kappa_d - E\kappa_d$. The nominal exchange rate depends on relative money supply in the two countries:

$$\hat{e} = \frac{\hat{m} - \hat{m}^*}{\rho(1-\gamma) + \gamma} \tag{5}$$

Agents' optimisation implies $\frac{M^i}{P} = \chi (C^i)^\rho$, so that consumption depends on the real money balance. Since monetary expansion directly increases Home consumption, the total spending Z depends on the 'world' money supply:

$$\hat{z} = \frac{\hat{m} + \hat{m}^*}{2\rho} \tag{6}$$

Using the properties of log-normal distributions and the limit $\chi \to 0$, the expected utilities of Home and Foreign agents can be expressed as:

$$
\begin{aligned}
EU &= E\widetilde{U}\exp[(1-\rho)\Omega(\rho)] & (7)\\
EU^{*} &= E\widetilde{U}^{*}\exp[(1-\rho)\Omega^{*}(\rho)] & (8)
\end{aligned}
$$

where $E\widetilde{U} = E\widetilde{U}^{*}$ denotes expected utilities in a flexible wage equilibrium.[3] The functions $\Omega(\rho)$ and $\Omega^{*}(\rho)$ reflect the effect of uncertainties on the expected utilities, and are defined as:

$$
\begin{aligned}
\Omega(\rho) &\equiv \Omega_w(\rho) + \Omega_d(\rho) & (9)\\
\Omega^{*}(\rho) &\equiv \Omega_w(\rho) - \Omega_d(\rho)
\end{aligned}
$$

where:

$$
\begin{aligned}
\Omega_w(\rho) = & -\frac{\nu}{2[\nu-(1-\rho)]^2}(\sigma^2_{\kappa_w}+\sigma^2_{\kappa_d}) + \frac{\lambda}{\nu-(1-\rho)} - \frac{\nu}{2}\sigma^2_z & (10)\\
& -\frac{\nu\left[\nu-(1-\gamma)^2(1-\rho)\right]\frac{\nu}{8}\sigma^2_{\epsilon} + \nu\sigma_{\kappa_w z} + \frac{\nu}{2}\sigma_{\kappa_d z}}{\nu-(1-\rho)}
\end{aligned}
$$

and

$$
\Omega_d(\rho) = -\frac{1-\gamma}{2}\left[\frac{\nu[\nu-(1-\rho)]\sigma_{z\epsilon} + \nu\sigma_{\kappa_w\epsilon} + 2\nu\sigma_{\kappa_d\epsilon}}{\nu-(1-\gamma)(1-\rho)}\right]. \qquad (11)
$$

Thus, the functions $\Omega_w(\rho)$ and $\Omega_d(\rho)$ are the symmetric and asymmetric components of the Home and Foreign expected utilities, respectively. An increase in $\Omega_w(\rho)$ makes both countries better off, whereas an increase in $\Omega_d(\rho)$ makes Home better off while making Foreign worse off. For example, both Home and Foreign dislike larger volatility in world demand, σ^2_z; but whereas Home dislikes a rise in $\sigma_{\kappa_w\epsilon}$, which worsens its terms of trade when the world productivity is low, a rise in $\sigma_{\kappa_w\epsilon}$ benefits Foreign as it improves its terms of trade. Since monetary policy affects ε and z, it influences the variance and covariance terms in $\Omega_w(\rho)$ and $\Omega_d(\rho)$.

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[3]

$$
E\widetilde{U} = E\widetilde{U}^{*} = \left[\frac{\nu\phi\theta-(1-\rho)(\phi-1)(\theta-1)}{\nu\phi\theta(1-\rho)}\right]\exp\left[\frac{(1-\rho)\omega}{\nu-(1-\rho)}\right]
$$

where ω and λ are defined as:

$$
\begin{aligned}
\omega &\equiv \log\left[\frac{(\phi-1)(\theta-1)}{\phi\theta}\right] - E\kappa + \frac{(1-\rho)}{2[\nu-(1-\rho)]}\sigma^2_{\kappa} - \lambda; \text{ and}\\
\lambda &= \frac{(1-\rho)\gamma\nu\left[(1-\frac{\gamma}{2})\nu-(1-\gamma)(1-\rho)\right]}{[\nu-(1-\rho)]\left[\nu-(1-\gamma)(1-\rho)\right]}\sigma^2_{\kappa_d}
\end{aligned}
$$

2.2 Monetary policy trade-offs

The Home central bank decides how to respond to the unanticipated 'difference' and 'world' productivity shocks by choosing the policy parameters δ_d and δ_w, and the Foreign central bank similarly chooses δ_d^* and δ_w^*. The presence of two sources of frictions in the model – nominal rigidity and missing market for state-contingent assets – means that central banks face a trade-off between gains from offsetting nominal wage rigidity and gains from international risk sharing. Monetary policy can offset unanticipated productivity shocks so as to achieve the flexible-wage equilibrium outcome. It can also be used as an international risk-sharing tool by altering the terms of trade to switch demand towards the country with higher productivity (expenditure switching effect), and by restraining demand when the world productivity is low (world aggregate demand effect).[4] But monetary policy does not eliminate distortions caused by monopolistic competition and therefore can only achieve the 'constrained' optimum, since central banks following pre-specified rules do not offset price mark-ups by surprising the agents.

The flexible wage equilibrium can be achieved if the monetary policy rules (3) and (4) target $\Omega_w(\rho) = \Omega_d(\rho) = 0$ by setting the policy parameters as follows[5]:

$$\delta_d^{flex} = \frac{\rho(1-\gamma)+\gamma}{v-(1-\gamma)(1-\rho)} = \delta_d^{*flex} \tag{12}$$

$$\delta_w^{flex} = \frac{\rho}{v-(1-\rho)} = \delta_w^{*flex} \tag{13}$$

In an uncoordinated (or Nash) game, the Home monetary authority sets δ_d and δ_w so as to maximise (7) and the Foreign central bank similarly chooses δ_d^* and δ_w^* to maximise (8). OR show that in a symmetric Nash equilibrium, Home and Foreign central banks set the policy parameters such that:

$$\delta_d^{Nash} = \frac{(\rho(1-\gamma)+\gamma)\left(1+(1-\gamma)\frac{\delta_d^{flex}}{\delta_w^{flex}}\right)}{(v-(1-\gamma)^2(1-\rho))+((1-\gamma)(v-(1-\rho))\frac{\delta_d^{flex}}{\delta_w^{flex}})} = \delta_d^{*Nash} \tag{14}$$

$$\delta_w^{Nash} = \frac{\rho}{v-(1-\rho)} = \delta_w^{*Nash} \tag{15}$$

In a cooperative game, the social planner sets δ_d, δ_w, δ_d^* and δ_w^* to maximise the world welfare, $EV = \frac{1}{2}EU + \frac{1}{2}EU^*$. The coordination gains arise from the asymmetric (or zero-sum) component in expected utilities, $\Omega_d(\rho)$: it is globally (Pareto) optimal to place zero weight on $\Omega_d(\rho)$ when setting monetary policy, but without cooperation the Home central bank tries to increase $\Omega_d(\rho)$ and the Foreign central bank tries to reduce it. OR show that in a cooperative equilibrium, a social

[4] This implies that monetary policy is procyclical in this model: Home monetary policy is tightened when there is a negative productivity shock to Home in order to improve its terms of trade.

[5] See OR (2000a) for derivation of (12) to (17).

planner would set the policy parameters such that:

$$\delta_d^{coop} = \frac{\rho(1-\gamma)+\gamma}{v-(1-\gamma)^2(1-\rho)} \quad (16)$$

$$\delta_w^{coop} = \frac{\rho}{v-(1-\rho)} \quad (17)$$

OR define (i) the 'stabilisation gain' as the welfare gain from setting monetary policy that targets flexible wage equilibrium, relative to a passive policy ($100 \times \left[\frac{\exp(\Omega^{flex})-\exp(\Omega^{const})}{\exp(\Omega^{const})}\right]$), and (ii) the 'coordination gain' as the welfare gain from moving from flexible wage policy to the cooperative equilibrium ($100 \times \left[\frac{\exp(\Omega^{coop})-\exp(\Omega^{flex})}{\exp(\Omega^{flex})}\right]$), where Ω^{const}, Ω^{flex}, Ω^{coop} are as defined in (9) and evaluated under $(\delta_d, \delta_w) = (0,0)$, $(\delta_d, \delta_w) = (\delta_d^{flex}, \delta_w^{flex})$ and $(\delta_d, \delta_w) = (\delta_d^{coop}, \delta_w^{coop})$, respectively. These welfare gains are defined as percentages of the mean flex-wage output level. Since the Nash equilibrium policy response lies between the flexible-wage and cooperative responses, the ratio of (ii)/(i) is the upper bound on the gains to cooperative versus Nash behaviour in rule setting. Based on simulations which assume that the productivity shocks across countries are uncorrelated ($\sigma_{\kappa\kappa^*} = 0$), OR conclude that under perfect information, such gains from international monetary coordination are small.

2.3 Robustness

Here, we briefly examine the robustness of OR's conclusion by simulating the model for different cross-country correlations of productivity shocks, $\sigma_{\kappa\kappa^*}$, while maintaining their calibration for other parameters: $\nu = 1.5$, $\gamma = 0.6$, and $\sigma_\kappa^2 = \sigma_{\kappa^*}^2 = 0.02$. Figure 1, which plots our simulation results for varying $\sigma_{\kappa\kappa^*}$ under this benchmark calibration, shows that coordination gains are relatively large when productivity shocks are negatively correlated across countries and small when they are positively correlated. This is because the scope for *ex-ante* risk sharing between countries is greatest when productivity shocks are negatively correlated (Figure 1, upper panel). However, we find that the coordination gains are still small relative to stabilisation gains when $\sigma_{\kappa\kappa^*} < 0$, confirming the generality of OR's results under different assumptions about the cross-country correlation of productivity shocks (see Figure 1, lower panel).

However, we find that Proposition 3 in OR (2000a, 2002) – that $\delta_d^{flex} > \delta_d^{Nash} > \delta_d^{coop}$ when $\rho < 1$ and $\delta_d^{flex} < \delta_d^{Nash} < \delta_d^{coop}$ when $\rho > 1$ – does not hold when $v = 1$. When $v = 1$, the non-cooperative monetary policy rule targets the flexible wage equilibrium, so that $\delta_d^{Nash} = \delta_d^{flex}$ and $\delta_w^{Nash} = \delta_w^{flex}$.[6]

[6] OR do not prove this proposition in their paper. It is straightforward to prove that when $v = 1$:

$$\delta_d^{Nash} = [1-(1-\gamma)(1-\rho)]\frac{2-\gamma}{[1-(1-\gamma)^2(1-\rho)]+\rho(1-\gamma)} = 1 = \delta_d^{flex}$$

Since $\delta_w^{flex} = \delta_w^{Nash}$ for any $\rho \geq 0$ (by Proposition 2, OR 2002a, 2002), the non-cooperative policy rule targets the flexible wage equilibrium when $v = 1$. Since OR (2002) only examine the case in which $v = 1$, Proposition 3 does not hold for the case discussed in that paper.

This is because when $v = 1$, the Home agents' marginal disutility from labour depends linearly on the stochastic Home productivity shock κ, so that the Home central bank does not react to Foreign productivity shocks and simply offsets unexpected domestic productivity shocks. And given this strategy of the Home central bank, the Foreign central bank does not have the incentives to deviate from targeting the flexible-wage equilibrium. The next section will demonstrate that when $v = 1$, the ability of the Home central bank to observe the Foreign productivity shock brings no welfare gains (or losses), precisely for the same reason.

3 The world of imperfect information

3.1 Set-up

We now introduce imperfect information into the OR model to analyse the welfare implications of information sharing between countries. As in OR, we assume that the Home central bank knows the probability distribution of Foreign productivity shocks when it sets the monetary policy rule in stage 1, and vice versa. But we modify OR's perfect information set-up by assuming that central banks can observe only the domestic productivity shock in stage 2. Since the Home central bank cannot observe the realised Foreign productivity shock, it updates its belief about the Foreign productivity shock κ^* after observing the Home productivity shock κ. Similarly, the Foreign central bank can only observe κ^* but not κ, and updates its belief about κ after observing κ^*.

This assumption captures the reality in which central banks are typically well-resourced to analyse the state of the domestic economy, but have limited capacity to understand the developments abroad. Indeed, central banks often rely on formal and informal information exchanges with other central banks in order to gain better insights about the states of other major economies. Introducing imperfect information in this fashion allows us to separate the welfare gains from two different types of international monetary cooperation – gains from sharing information with other central banks, and gains from implementing coordinated (Pareto-improving) policies.

If neither central bank can observe the true κ_d and κ_w, each forms a belief about these after it observes the domestic productivity shock and reacts to its updated 'best guesses' of κ_d and κ_w. Denoting the Home central bank's updated ('posterior') belief about κ_d and κ_w as $\widetilde{\kappa}_d$ and $\widetilde{\kappa}_w$, and the Foreign central bank's belief as $\widetilde{\kappa}_d^*$ and $\widetilde{\kappa}_w^*$, these can be expressed as:

$$\widetilde{\kappa}_d = \frac{\widehat{\kappa} - (E(\kappa^*|\kappa) - E(\kappa^*))}{2} \tag{18}$$

$$\widetilde{\kappa}_d^* = \frac{(E(\kappa|\kappa^*) - E(\kappa)) - \hat{\kappa}^*}{2} \tag{19}$$

$$\widetilde{\kappa}_w = \frac{\widehat{\kappa} + (E(\kappa^*|\kappa) - E(\kappa^*))}{2} \tag{20}$$

$$\widetilde{\kappa}_w^* = \frac{(E(\kappa|\kappa^*) - E(\kappa)) + \hat{\kappa}^*}{2} \tag{21}$$

where $\hat{\kappa} = \kappa - E(\kappa)$ and $\hat{\kappa}^* = \kappa^* - E(\kappa^*)$. In general, $\widetilde{\kappa}_d \neq \widetilde{\kappa}_d^*$ and $\widetilde{\kappa}_w \neq \widetilde{\kappa}_w^*$ because the two central banks form their beliefs about κ_d and κ_w based on different information sets: the Home central bank only observes the Home productivity shock, whereas the Foreign central bank only observes the Foreign shock. Under these assumptions, the Home and Foreign monetary policy rules are characterised as:

$$\widetilde{m} = -\delta_d \widetilde{\kappa}_d - \delta_w \widetilde{\kappa}_w \tag{22}$$

$$\widetilde{m}^* = \delta_d^* \widetilde{\kappa}_d^* - \delta_w^* \widetilde{\kappa}_w^* \tag{23}$$

We assume that each central bank updates its belief about the other country's productivity shock using the least-squares ('best guess') estimation procedure, so that the Home central bank's updated belief about the Foreign shock κ^*, conditional on the observed Home productivity shock κ, is expressed as:

$$E(\kappa^*|\kappa) = E(\kappa^*) - \frac{\sigma_{\kappa\kappa^*}}{\sigma_\kappa^2}\left(E(\kappa) - \kappa\right) = E(\kappa^*) + \frac{\sigma_{\kappa\kappa^*}}{\sigma_\kappa^2}\hat{\kappa}$$

Similarly, the Foreign central bank's conditional expectation about the Home shock $E(\kappa|\kappa^*)$ is:

$$E(\kappa|\kappa^*) = E(\kappa) - \frac{\sigma_{\kappa\kappa^*}}{\sigma_{\kappa^*}^2}\left(E(\kappa^*) - \kappa^*\right) = E(\kappa) + \frac{\sigma_{\kappa\kappa^*}}{\sigma_{\kappa^*}^2}\hat{\kappa}^*$$

Using the above expressions, we can rewrite (18) to (21) as:

$$\begin{aligned}
\widetilde{\kappa}_d &= \left(1 - \frac{\sigma_{\kappa\kappa^*}}{\sigma_\kappa^2}\right)\frac{\hat{\kappa}}{2} = (1-q)\frac{\hat{\kappa}}{2} && (24)\\
\widetilde{\kappa}_d^* &= -\left(1 - \frac{\sigma_{\kappa\kappa^*}}{\sigma_{\kappa^*}^2}\right)\frac{\hat{\kappa}^*}{2} = -(1-q)\frac{\hat{\kappa}^*}{2} && (25)\\
\widetilde{\kappa}_w &= \left(1 + \frac{\sigma_{\kappa\kappa^*}}{\sigma_\kappa^2}\right)\frac{\hat{\kappa}}{2} = (1+q)\frac{\hat{\kappa}}{2} && (26)\\
\widetilde{\kappa}_w^* &= \left(1 + \frac{\sigma_{\kappa\kappa^*}}{\sigma_{\kappa^*}^2}\right)\frac{\hat{\kappa}^*}{2} = (1+q)\frac{\hat{\kappa}^*}{2} && (27)
\end{aligned}$$

where $q \equiv \frac{\sigma_{\kappa\kappa^*}}{\sigma_\kappa^2} = \frac{\sigma_{\kappa\kappa^*}}{\sigma_{\kappa^*}^2}$. Substituting these into (22) and (23), the Home and Foreign monetary policy rules under imperfect information can be rewritten as:

$$\begin{aligned}
\widetilde{m} &= -\Delta\left(\frac{\hat{\kappa}}{2}\right) && (28)\\
\widetilde{m}^* &= -\Delta^*\left(\frac{\hat{\kappa}^*}{2}\right)
\end{aligned}$$

where $\Delta \equiv (1-q)\,\delta_d + (1+q)\,\delta_w$ and $\Delta^* \equiv (1-q)\,\delta_d^* + (1+q)\,\delta_w^*$. Since central banks cannot observe productivity shocks in the other country, their monetary policy rules can only respond to domestic productivity shocks, taking into account the correlation between domestic and foreign productivity shocks via q.

Using (5) and (6), the shocks to the exchange rate $\tilde{e}$ and the spending measured in units of tradables $\tilde{z}$ can be written as:

$$\tilde{e} = \frac{\widetilde{m} - \widetilde{m}^*}{1-(1-\gamma)(1-\rho)} = \frac{-[\Delta\hat{\kappa} - \Delta^*\hat{\kappa}^*]}{2[1-(1-\gamma)(1-\rho)]} \quad (29)$$

$$\tilde{z} = \frac{\tilde{m} + \tilde{m}^*}{2\rho} = \frac{-[\Delta\hat{\kappa} + \Delta^*\hat{\kappa}^*]}{4\rho} \quad (30)$$

In a non-cooperative ('Nash') game with imperfect information, the Home and Foreign central banks set the policy parameter Δ and Δ^* respectively to maximise their domestic agents' expected utilities, where Ω_w and Ω_d are computed under the assumption that the exchange rate and the spending measured in traded goods are determined by (29) and (30). Denoting these as $\Omega_w^{Nash-I}(\rho)$ and $\Omega_d^{Nash-I}(\rho)$, the Nash equilibrium under imperfect information solves the following first order condition for the Home country:

$$\frac{\partial\left[\Omega_w^{Nash-I}(\rho) + \Omega_d^{Nash-I}(\rho)\right]}{\partial\Delta} = 0$$

Solving the above for Δ, the imperfect information Nash equilibrium is given by (see Appendix A1 for derivation):

$$\Delta^{Nash-I} = \frac{2\rho t\left[(1+q)ts + \rho(1-q)s + \rho(1-\gamma)(1+q)u + (1-\gamma)(1-q)ut\right]}{(1+q)ust^2 + \rho^2(1-q)(v-(1-\gamma)^2(1-\rho))s + 2\rho(1-\gamma)u^2t} \quad (31)$$

where $s \equiv v-(1-\gamma)(1-\rho)$, $t \equiv 1-(1-\gamma)(1-\rho)$ and $u \equiv v-(1-\rho)$. By symmetry, $\Delta^{Nash-I} = \Delta^{*Nash-I}$.

3.2 Welfare analysis

To conduct welfare analysis, we simulate the model under the following four different assumptions:

(i) passive monetary policy ($\delta_d = \delta_w = 0$);

(ii) self-oriented (Nash equilibrium) monetary policy under imperfect information ($\Delta = \Delta^{Nash-I}$);

(iii) self-oriented monetary policy under perfect information ($\delta_d = \delta_d^{Nash}$ and $\delta_w = \delta_w^{Nash}$); and

(iv) coordinated monetary policy under perfect information ($\delta_d = \delta_d^{coop}$ and $\delta_w = \delta_w^{coop}$).

We then define the following welfare gains:

(a) *stabilisation gains under imperfect information* as $100 \times \left[\frac{\exp(\Omega^{Nash-I}) - \exp(\Omega^{const})}{\exp(\Omega^{const})}\right]$ (difference between (i) and (ii));

(b) *information sharing gains* as $100 \times \left[\frac{\exp(\Omega^{Nash-PI}) - \exp(\Omega^{Nash-II})}{\exp(\Omega^{Nash-II})}\right]$ (difference between (ii) and (iii)); and

(c) *coordination gains under perfect information* as $100 \times \left[\frac{\exp(\Omega^{coop}) - \exp(\Omega^{Nash-PI})}{\exp(\Omega^{Nash-PI})}\right]$ (difference between (iii) and (iv)).

Note that $\Omega^{Nash-PI}$ is (9) evaluated at the perfect information Nash equilibrium, and $\Omega^{Nash-II}$ is the same evaluated at the imperfect information Nash equilibrium. These definitions allow us to separate out the gains from international cooperation into information sharing gains and monetary coordination gains.[7]

We begin by exploring the gains from information sharing across countries. We find that in certain special cases, the gains from information sharing are zero:

Proposition 1 *Under symmetry ($\sigma_\kappa^2 = \sigma_{\kappa^*}^2$), the gains from information sharing are zero if one of the following conditions hold: (i) $\rho = 1$, (ii) $v = 1$, (iii) $q = 1$, or (iv) $q = -1$.*
Proof. *See Appendix A2.* ■

All of the above results have intuitive explanations. The self-oriented policy rule under perfect information, pinned down by (14) and (15), implies that when $\rho = 1$ or $v = 1$, the Home central bank does not react to the Foreign productivity shock $\hat{\kappa}^*$ at all even if it can observe it (and vice versa), since $\delta_d^{Nash} = \delta_w^{Nash}$. In fact, central banks simply target the flexible-wage equilibrium when $\rho = 1$ or $v = 1$, and implementing this policy rule requires information about the domestic productivity shocks only.[8] So naturally, there are no welfare losses from imperfect information in these cases.

When $q = 1$ or $q = -1$, the productivity shocks in the Home and Foreign countries are perfectly (positively or negatively) correlated, so that the Home central bank can infer the Foreign productivity shock perfectly by observing the Home productivity shock (and vice versa). Thus, the unobservability of foreign shocks has no welfare consequences in these cases.

When $\rho \neq 1$, $v \neq 1$, $q \neq 1$ and $q \neq -1$, information sharing can produce welfare gains or losses depending on the value of parameters. The welfare gains from information sharing under the benchmark parameterisation ($v = 1.5$, $\gamma = 0.6$, $\sigma_\kappa^2 = \sigma_{\kappa^*}^2 = 0.02$, $\sigma_{\kappa\kappa^*} = 0$ following Obstfeld and Rogoff, 2000a) are shown in the second panel of Figure 2. Somewhat surprisingly, the gains from information sharing are actually *negative* under this parameterisation. Coordination gains (under perfect information), though always positive, are quantitatively insignificant.

Why does information sharing lead to welfare losses? An intuitive explanation is that better information leads to welfare gains if and only if the extra knowledge encourages central bankers to move closer to the cooperative solution; however, there is no guarantee that this will always be the

[7] We have chosen to use $\Omega^{Nash-PI}$ instead of Ω^{flex} in order to derive the exact size of coordination gains rather than their upper bounds, as OR have done. In practice, replacing $\Omega^{Nash-PI}$ with Ω^{flex}, as in OR, has little impact on the quantitative results of our simulations, as the policy rule in the perfect information Nash equilibrium is very close to the policy rule that targets the flexible wage equilibrium.

[8] This is implied by our Proposition 1 above and Proposition 2 in OR (2000a, 2002).

case. To illustrate this point, we rewrite the monetary policy rule under perfect information (3) as a function of Home and Foreign productivity shocks:

$$\widehat{m} = -\left(\frac{\delta_d + \delta_w}{2}\right)\hat{\kappa} - \left(\frac{\delta_w - \delta_d}{2}\right)\hat{\kappa}^* \tag{32}$$

We find that for a range of parameters, $-\left(\frac{\delta_w^{coop} - \delta_d^{coop}}{2}\right) > 0$ whereas $-\left(\frac{\delta_w^{Nash} - \delta_d^{Nash}}{2}\right) < 0$. In other words, without international coordination, the Home central bank tightens monetary policy in response to a negative Foreign productivity shock ($\hat{\kappa}^* > 0$), even though it is globally optimal for central banks to loosen monetary policy in response to a negative productivity shock abroad. But if it cannot observe Foreign productivity shocks, Home monetary authority cannot react to Foreign shocks at all. Obviously, that policy is welfare improving relative to the self-oriented policy under perfect information which reacts to foreign shocks in the opposite direction as the cooperative policy.

In this model, Home monetary expansion has two opposing effects on the demand for Foreign goods: on the one hand, it increases demand for Foreign goods by stimulating the world aggregate demand, but on the other hand, it induces the Home currency to depreciate against the Foreign currency and thereby switches the world demand to Home goods from Foreign goods. Hence, the globally optimal response by the Home central bank to a negative productivity shock abroad (which makes Foreigners less willing to work) depends on whether the need to loosen Home monetary policy to improve the Foreign terms of trade and allow Foreigners to import more (expenditure switching consideration) outweighs the need to tighten Home monetary policy to lower the world demand (world demand consideration). Under the self-oriented policy with perfect information, the Home central bank tightens monetary policy in response to a negative productivity shock abroad (or does not respond at all when $\rho = 1$ or $\upsilon = 1$) because it places a sub-optimal weight on the expenditure switching consideration from a global perspective. So information sharing gains are positive only in those cases where the world demand consideration dominates the terms of trade consideration in setting the globally optimal rule. In these cases only, the self-oriented policy under perfect information is closer to the coordinated policy rule than the self-oriented policy under imperfect information. But precisely because self-oriented policy mimics coordinated policy, the additional gains from coordination are small in these cases.

This is graphically illustrated in Figure 3, which shows the Home central bank's response to the domestic and foreign productivity shocks under the benchmark parameterisation for different values of ρ. The upper panel shows that without cooperation, Home central bank responds less aggressively to domestic productivity shocks than what would be globally optimal; but the knowledge of the Foreign shock has little influence on the way it responds to a domestic shock. The lower panel shows that under cooperation the Home central bank to loosen monetary policy in response to a negative Foreign productivity shock, whereas without cooperation it tightens it. So even though the globally optimal policy rule under this parameterisation requires the Home central bank to loosen monetary policy in order to improve the Foreign country's terms of trade when the latter is hit by a negative productivity shock (and vice versa), the Home central bank instead tightens its policy in order to restrain the world demand and improve its own terms of trade. Since the knowledge of the Foreign productivity shocks can make the Home central bank react in the *opposite* direction relative to the globally optimal policy rule, better information can be welfare reducing.

3.3 Determinants of welfare gains

What factors influence the magnitude of these welfare gains? Model simulations reveal that the magnitude of welfare gains from information sharing and coordination depends on the combinations of ρ and v – i.e. the parameters characterising agents' risk aversion and disutility from labour. To illustrate this, Figure 4 shows stabilisation gains under imperfect information, information sharing gains, and coordination gains under perfect information. Figure 5 plots the Home central bank's response to a negative productivity shock abroad under perfect information Nash equilibrium (upper panel) and coordinated equilibrium (lower panel) under varying combinations of ρ and v, while the remaining parameters are specified as in the benchmark calibration ($\gamma = 0.6$, $\sigma_{\kappa}^2 = \sigma_{\kappa^*}^2 = 0.02$, $\sigma_{\kappa\kappa^*} = 0$).

In general, the lower v (i.e. the less convex the marginal disutility of labour), the lower the threshold degree of risk aversion ρ at which the globally-optimal Home monetary response to a negative Foreign productivity shock becomes expansionary – i.e. $-\left(\frac{\delta_w^{coop} - \delta_d^{coop}}{2}\right)$ in (32)) becomes positive (Figure 5, lower panel). Intuitively, when the marginal disutility from additional hours worked does not rise rapidly (v is low), it is globally optimal to shift the world demand to the Home country and make the Home agents work harder when Foreign is hit by a negative productivity shock, rather than contract the world aggregate demand – i.e. the terms of trade consideration dominates the aggregate demand consideration. Conversely, when the marginal disutility from work rises very rapidly (v is large), it is globally optimal to contract the world aggregate demand rather than make the Home agents work harder.

But since the self-oriented policy under perfect information places sub-optimal weight on the terms of trade consideration, the coordinated and Nash solutions deviate from each other when the terms of trade consideration dominates the world demand consideration in setting the coordinated policy rule. Consequently, information sharing gain tends to be negative in these cases (when v is small and ρ is large) while gains from coordination tends to be relatively large (see Figure 4). In contrast, when the world aggregate demand consideration dominates the terms of trade consideration in setting the globally optimal policy rule (when v is large and ρ is small), the Nash solution under perfect information is close to the coordinated solution, so that the gains from information sharing are positive – but gains from coordination are low precisely for the same reason.

Gains from setting a self-oriented monetary policy rule under imperfect information are generally positive and large compared to the gains from information sharing and cooperation (Figure 4). This suggests that countries can potentially achieve large welfare gains from setting clear and time-consistent policy frameworks even if they do not have perfect information about the world economy.

4 Conclusions

There are three key findings from our analysis. First, setting a self-oriented monetary policy rule which responds to unexpected shocks in a predictable manner leads to welfare gains, even if central banks do not have perfect information about the world economy. Our analysis reinforces the generality of Ghosh and Masson's (1991) conclusions that activist monetary policy rule can achieve a superior outcome relative to a passive policy in a micro-founded 'second generation' model. Second, we find that better information about the state of the world economy has ambiguous welfare implications in this stylised model. On the one hand, better information allows policy makers to respond appropriately to common shocks; but on the other hand, it could also encourage them to adjust policies to their advantage at the expense of hurting the foreign economies. Third, our simulations show that gains from international monetary coordination under perfect information are greatest when productivity shocks are negatively correlated between countries. However, the total gains from international cooperation – involving both information sharing and implementing coordinated policies – are nevertheless relatively small.

We thus conclude that better information, by itself, does not necessarily guarantee Pareto-improving behaviour by central banks. This suggests that international dialogue would be more effective if supported by institutions which encourage central banks to take into account the policy spillovers on the basis of better information. However, the quantitative gains from information sharing are likely to depend on the specific assumptions of the model. First, achieving the flexible-wage equilibrium through monetary policy in our model requires information about domestic shocks only, so that imperfect information about foreign productivity shocks does not affect the central banks' ability to achieve the flexible-wage equilibrium. This is likely to be an important reason why information sharing gains (or losses) are quantitatively small in our simulations. Our conjecture is that the gains from information sharing could be larger if production by domestic firms relies on imported inputs produced by foreign labour, such that achieving the flexible-wage equilibrium requires information about foreign productivity shocks. Second, our result that information sharing and coordination gains are small relative to stabilisation gains may change once we relax the assumption of perfect exchange rate pass-through. Corsetti and Pesenti's (2005) analysis shows that the welfare gains from international coordination depend non-linearly on the degree of exchange rate pass-through, and thus raises the possibility that the gains from information sharing in our model could be larger if the exchange rate pass-through is less than perfect. These are possible avenues for future research.

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A Appendix

A.1 Solving for Nash equilibrium under imperfect information:

From (29) and (30), we obtain (since v does not enter $\tilde{e}$ and $\tilde{z}$, these remain the same as in the case when $v = 1$):

$$
\begin{aligned}
\sigma_e^2 &= \frac{\Delta^2\sigma_\kappa^2 + \Delta^{*2}\sigma_{\kappa^*}^2 - 2\Delta\Delta^*\sigma_{\kappa\kappa^*}}{4(1-(1-\gamma)(1-\rho))^2} \\
\sigma_z^2 &= \frac{\Delta^2\sigma_\kappa^2 + \Delta^{*2}\sigma_{\kappa^*}^2 + 2\Delta\Delta^*\sigma_{\kappa\kappa^*}}{16\rho^2} \\
\sigma_{\kappa e} &= \frac{-\Delta\sigma_\kappa^2 + \Delta^*\sigma_{\kappa\kappa^*}}{2(1-(1-\gamma)(1-\rho))};\ \sigma_{\kappa^* e} = \frac{\Delta^*\sigma_{\kappa^*}^2 - \Delta\sigma_{\kappa\kappa^*}}{2(1-(1-\gamma)(1-\rho))} \\
\sigma_{\kappa z} &= \frac{-\Delta\sigma_\kappa^2 - \Delta^*\sigma_{\kappa\kappa^*}}{4\rho};\ \sigma_{\kappa^* z} = \frac{-\Delta^*\sigma_{\kappa^*}^2 - \Delta\sigma_{\kappa\kappa^*}}{4\rho} \\
\sigma_{ze} &= \frac{\Delta^2\sigma_\kappa^2 - \Delta^{*2}\sigma_{\kappa^*}^2}{8\rho\,(1-(1-\gamma)(1-\rho))}
\end{aligned}
$$

To derive the imperfect information Nash equilibrium Δ, take the first order condition of (7) using the above relationships:

$$
\begin{aligned}
\frac{\partial EU}{\partial \Delta} &= \frac{\partial \Omega_w(\rho)}{\partial \Delta} + \frac{\partial \Omega_d(\rho)}{\partial \Delta} \\
&= -\frac{v}{2}\frac{\partial \sigma_z^2}{\partial \Delta} - \frac{v(v-(1-\gamma)^2(1-\rho))}{8\,(v-(1-\rho))}\frac{\partial \sigma_e^2}{\partial \Delta} \\
&\quad - \frac{v}{2\,(v-(1-\rho))}\left(\frac{\partial \sigma_{\kappa z}}{\partial \Delta} + \frac{\partial \sigma_{\kappa^* z}}{\partial \Delta}\right) - \frac{v}{4\,(v-(1-\rho))}\left(\frac{\partial \sigma_{\kappa e}}{\partial \Delta} - \frac{\partial \sigma_{\kappa^* e}}{\partial \Delta}\right) \\
&\quad - \frac{(1-\gamma)v(v-(1-\rho))}{2[v-(1-\gamma)(1-\rho)]}\frac{\partial \sigma_{ze}}{\partial \Delta} - \frac{(1-\gamma)v}{4[v-(1-\gamma)(1-\rho)]}\left(\frac{\partial \sigma_{\kappa e}}{\partial \Delta} + \frac{\partial \sigma_{\kappa^* e}}{\partial \Delta}\right) \\
&\quad - \frac{(1-\gamma)v}{2\,(v-(1-\gamma)(1-\rho))}\left(\frac{\partial \sigma_{\kappa z}}{\partial \Delta} - \frac{\partial \sigma_{\kappa^* z}}{\partial \Delta}\right) \\
&= 0
\end{aligned}
$$

Using symmetry ($\sigma_\kappa = \sigma_{\kappa^*}$, and $\Delta = \Delta^*$ in equilibrium), we obtain:

$$
\begin{aligned}
\frac{\partial \sigma_z^2}{\partial \Delta} &= \frac{\Delta\sigma_\kappa^2 + \Delta^*\sigma_{\kappa\kappa^*}}{8\rho^2} = \frac{\Delta\left(\sigma_\kappa^2 + \sigma_{\kappa\kappa^*}\right)}{8\rho^2} \\
\frac{\partial \sigma_e^2}{\partial \Delta} &= \frac{\Delta\sigma_\kappa^2 - \Delta^*\sigma_{\kappa\kappa^*}}{2(1-(1-\gamma)(1-\rho))^2} = \frac{\Delta\left(\sigma_\kappa^2 - \sigma_{\kappa\kappa^*}\right)}{2(1-(1-\gamma)(1-\rho))^2} \\
\frac{\partial \sigma_{\kappa z}}{\partial \Delta} + \frac{\partial \sigma_{\kappa^* z}}{\partial \Delta} &= \frac{-\sigma_\kappa^2 - \sigma_{\kappa\kappa^*}}{4\rho} \\
\frac{\partial \sigma_{\kappa z}}{\partial \Delta} - \frac{\partial \sigma_{\kappa^* z}}{\partial \Delta} &= \frac{-\sigma_\kappa^2 + \sigma_{\kappa\kappa^*}}{4\rho} \\
\frac{\partial \sigma_{\kappa e}}{\partial \Delta} + \frac{\partial \sigma_{\kappa^* e}}{\partial \Delta} &= \frac{-\sigma_\kappa^2 - \sigma_{\kappa\kappa^*}}{2(1-(1-\gamma)(1-\rho))} \\
\frac{\partial \sigma_{\kappa e}}{\partial \Delta} - \frac{\partial \sigma_{\kappa^* e}}{\partial \Delta} &= \frac{-\sigma_\kappa^2 + \sigma_{\kappa\kappa^*}}{2(1-(1-\gamma)(1-\rho))} \\
\frac{\partial \sigma_{ze}}{\partial \Delta} &= \frac{\Delta\sigma_\kappa^2}{4\rho\,(1-(1-\gamma)(1-\rho))}
\end{aligned}
$$

Inserting the above, and defining $s \equiv v-(1-\gamma)(1-\rho)$, $t \equiv 1-(1-\gamma)(1-\rho)$ and $u \equiv v-(1-\rho)$, the first-order condition becomes:

$$\begin{aligned}
\frac{\partial EU^{Nash-I}}{\partial \Delta} &= -\frac{\Delta v\left(\sigma_\kappa^2+\sigma_{\kappa\kappa^*}\right)}{16\rho^2}-\frac{v(v-(1-\gamma)^2(1-\rho))\Delta\left(\sigma_\kappa^2-\sigma_{\kappa\kappa^*}\right)}{16ut^2} \\
&\quad +\frac{v(\sigma_\kappa^2+\sigma_{\kappa\kappa^*})}{8\rho u}+\frac{v(\sigma_\kappa^2-\sigma_{\kappa\kappa^*})}{8ut}-\frac{(1-\gamma)v(u)\Delta\sigma_\kappa^2}{8\rho ts} \\
&\quad +\frac{(1-\gamma)v(\sigma_\kappa^2+\sigma_{\kappa\kappa^*})}{8ts}+\frac{(1-\gamma)v\left(\sigma_\kappa^2-\sigma_{\kappa\kappa^*}\right)}{8\rho s} \\
&= 0
\end{aligned}$$

Replacing $q=\frac{\sigma_{\kappa\kappa^*}}{\sigma_\kappa^2}$ and dividing both sides by $\frac{\sigma_\kappa^2}{8}v$:

$$\begin{aligned}
& -\frac{\Delta(1+q)}{2\rho^2}-\frac{(v-(1-\gamma)^2(1-\rho))\Delta(1-q)}{2ut^2}+\frac{(1+q)}{\rho u} \\
& +\frac{(1-q)}{ut}-\frac{(1-\gamma)(u)\Delta}{\rho ts}+\frac{(1-\gamma)(1+q)}{ts}+\frac{(1-\gamma)(1-q)}{\rho s} \\
= \; & 0
\end{aligned}$$

Solving for Δ, we obtain Δ^{Nash-I} as in (31).

A.2 Proof of Proposition 1

The gains from information sharing is zero if $\Omega^{Nash-P}=\Omega^{*Nash-I}$ or equivalently if $\Omega^{Nash-P}-\Omega^{Nash-I}=0$, where these are defined as:

$$\begin{aligned}
\Omega^{Nash-P} &= -\left(\frac{v(\sigma_{\kappa_w}^2+\sigma_{\kappa_d}^2)}{2(v-(1-\rho))^2}\right)+\frac{\lambda}{v-(1-\rho)}-\frac{v}{2}\left(\frac{(2\delta_w^{Nash})^2}{4\rho^2}\sigma_{\kappa_w}^2\right) \\
&\quad -\frac{1}{v-(1-\rho)}\left\{\frac{v}{8}(v-(1-\gamma)^2(1-\rho))\left(\frac{2\delta_d^{Nash}}{1-(1-\gamma)(1-\rho)}\right)^2\sigma_{\kappa_d}^2\right. \\
&\quad \left.-\frac{v\left(2\delta_w^{Nash}\right)}{2\rho}\sigma_{\kappa_w}^2+\frac{v}{2}\left(-\frac{2\delta_d^{Nash}}{1-(1-\gamma)(1-\rho)}\sigma_{\kappa_d}^2\right)\right\} \\
\Omega^{Nash-I} &= -\left(\frac{v(\sigma_{\kappa_w}^2+\sigma_{\kappa_d}^2)}{2(v-(1-\rho))^2}\right)+\frac{\lambda}{v-(1-\rho)}-\frac{v}{2}\left(\frac{\left(\Delta^{Nash-I}\right)^2}{4\rho^2}\sigma_{\kappa_w}^2\right) \\
&\quad -\frac{1}{v-(1-\rho)}\left\{\frac{v}{8}(v-(1-\gamma)^2(1-\rho))\left(\frac{\Delta^{Nash-I}}{1-(1-\gamma)(1-\rho)}\right)^2\sigma_{\kappa_d}^2\right. \\
&\quad \left.-\frac{v\Delta^{Nash-I}}{2\rho}\sigma_{\kappa_w}^2+\frac{v}{2}\left(-\frac{\Delta^{Nash-I}}{1-(1-\gamma)(1-\rho)}\sigma_{\kappa_d}^2\right)\right\}
\end{aligned}$$

We also define $\sigma^2_{\kappa_w} = \frac{\sigma^2_\kappa}{4} + \frac{\sigma^2_{\kappa^*}}{4} + \frac{\sigma^2_{\kappa\kappa^*}}{2}$, $\sigma^2_{\kappa_w} = \frac{\sigma^2_\kappa}{4} + \frac{\sigma^2_{\kappa^*}}{4} - \frac{\sigma^2_{\kappa\kappa^*}}{2}$ and $q = \frac{\sigma_{\kappa\kappa^*}}{\sigma^2_\kappa}$. Using the above, and the definitions $s \equiv v - (1-\gamma)(1-\rho)$, $t \equiv 1 - (1-\gamma)(1-\rho)$, and $u \equiv v - (1-\rho)$, it can be shown that $\Omega^{Nash-P} = \Omega^{Nash-I}$ if:

$$\begin{aligned} & \sigma^2_{\kappa_w}\left\{-\frac{v}{2\rho^2}\left(\left(\delta_w^{Nash}\right)^2 - \left(\frac{\Delta^{Nash-I}}{2}\right)^2\right) + \frac{v}{\rho u}\left(\delta_w^{Nash} - \frac{\Delta^{Nash-I}}{2}\right)\right\} \\ & +\sigma^2_{\kappa_d}\left\{-\frac{v(v-(1-\gamma)^2(1-\rho))}{2ut^2}\left(\left(\delta_d^{Nash}\right)^2 - \left(\frac{\Delta^{Nash-I}}{2}\right)^2\right) + \frac{v}{ut}\left(\delta_d^{Nash} - \frac{\Delta^{Nash-I}}{2}\right)\right\} \\ = \ & 0 \end{aligned} \tag{33}$$

Information sharing gain is equal to zero if the equality (33) holds.

(i) If $\rho = 1$, it is straightforward to show that $\delta_d^{Nash} = \delta_w^{Nash} = \frac{1}{v}$ (also $\delta_d^{flex} = \delta_w^{flex} = \frac{1}{v}$). Using some algebra, it can also be shown that $\Delta^{Nash-I} = \frac{2}{v}$, so that $\delta_d^{Nash} = \delta_w^{Nash} = \frac{\Delta}{2}$. Hence (33) holds and so $\Omega^{Nash-P} = \Omega^{Nash-I}$ (QED).

(ii) If $v = 1$, $\delta_d^{Nash} = \delta_w^{Nash} = 1$ and $\Delta = 2$.[9] Since $\delta_d^{Nash} = \delta_w^{Nash} = \frac{\Delta}{2}$, (33) holds and so $\Omega^{Nash-P} = \Omega^{Nash-I}$ (QED).

(iii) If $q = 1$, then $\sigma^2_{\kappa_d} = 0$. Substituting in $q = 1$ and simplifying Δ,

$$\begin{aligned} \Delta^{Nash-I} &= \frac{\rho\,(2ts + 2\rho(1-\gamma)u)}{ust + \rho(1-\gamma)u^2} \\ &= \frac{2\rho}{u} = 2\delta_w^{*Nash} \end{aligned}$$

Hence, $\sigma^2_{\kappa_w}\left(-\frac{v}{2\rho^2}\left(\left(\delta_w^{Nash}\right)^2 - \left(\frac{\Delta^{Nash-I}}{2}\right)^2\right) + \frac{v}{\rho u}\left(\delta_w^{Nash} - \left(\frac{\Delta^{Nash-I}}{2}\right)\right)\right) = 0$ and (33) holds (QED).

(iv) If $q = -1$, then $\sigma^2_{\kappa_w} = 0$. Substituting in $q = -1$ and simplifying Δ,

$$\begin{aligned} \Delta &= \left(\frac{\rho s + \rho(1-\gamma)(1+q)u + (1-\gamma)ut}{\rho^2(v - (1-\gamma)^2\,(1-\rho))s + \rho(1-\gamma)u^2 t}\right) * (2\rho t) \\ &= 2\delta_d^{*Nash} \end{aligned}$$

Hence, $\sigma^2_{\kappa_d}\left(-\frac{v(v-(1-\gamma)^2(1-\rho))}{2ut^2}\left(\left(\delta_d^{*Nash}\right)^2 - \left(\frac{\Delta}{2}\right)^2\right) + \frac{v}{ut}\left(\delta_d^{*Nash} - \left(\frac{\Delta}{2}\right)\right)\right) = 0$ and (33) holds (QED).

[9] It is also straightforward to demonstrate that Proposition 3 in Obstfeld and Rogoff (2002) is incorrect. When $v = 1$, δ_d^{*Nash} and δ_d^{*flex} both simplify to 1, so that $\delta_d^{*Nash} = \delta_d^{*flex} = 1$.

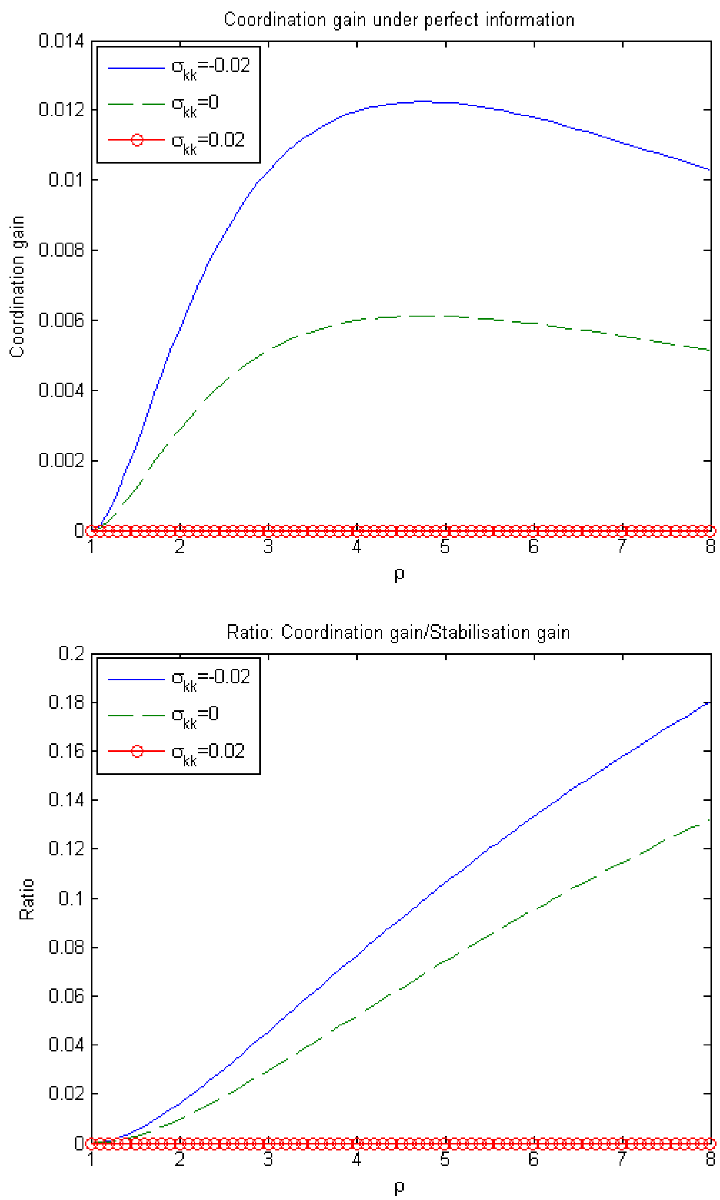

Figure 1: Cooperation gains and Coordination gains/Stabilisation gains ratios under different cross-country correlation of productivity shocks

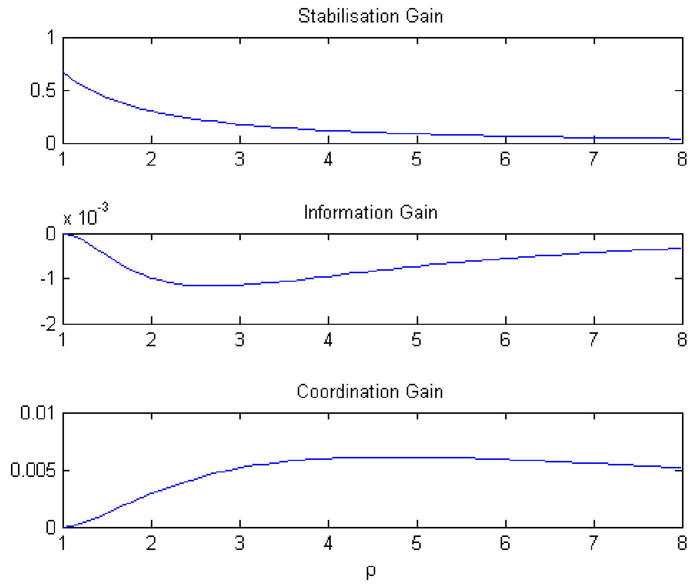

Figure 2: Gains from stabilisation, information sharing and cooperation

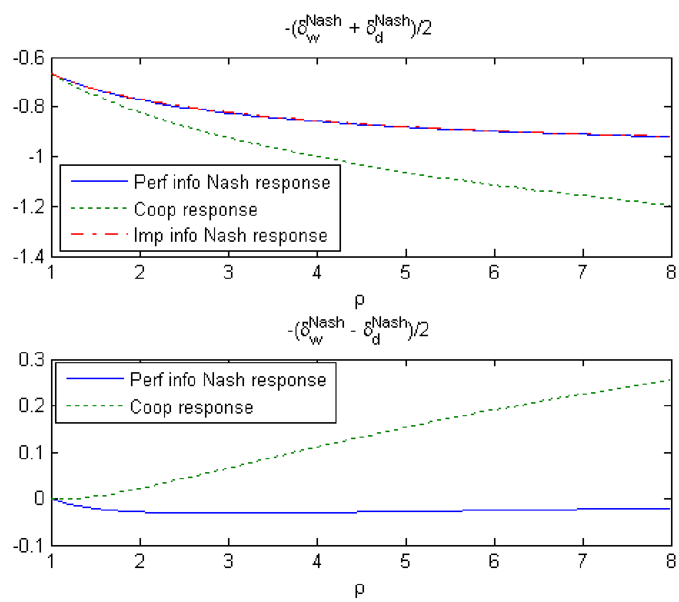

Figure 3: Policy response to a negative domestic productivity shock (upper panel) and a negative foreign productivity shock (lower panel)

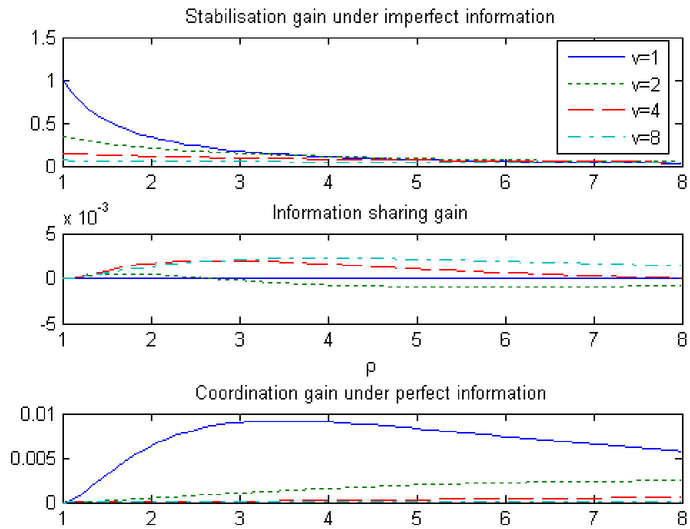

Figure 4: Welfare gains under varying ρ and ν

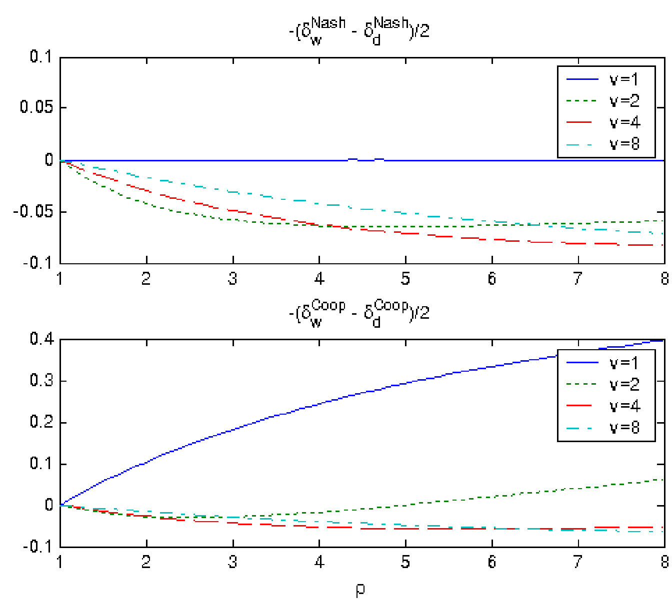

Figure 5: Policy responses to a negative foreign productivity shock under varying ρ and ν