OPTIMAL MONETARY POLICY COORDINATION FOR OPEN ECONOMIES WITH PRODUCTION FRAGMENTATION AND DOLLAR-INVOICED TRADE

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ABSTRACT

This paper proposes two novel views of optimal monetary policy coordination for open economies that are linked vertically and sequentially through production fragmentation across borders. We first show that the type not the size of trade matters for welfare evaluation of policy coordination. Welfare gains from policy coordination are particularly sizeable when (i) the member economies vertically specialise along different value chains of production, complementing each other through vertical trade; and (ii) countries occupying value chains that are closer to final goods consumer have dominant weight in joint welfare loss function. We then develop a view of optimal monetary policy coordination as one that involves competing objectives of optimal input allocation and optimal consumption allocation due to production fragmentation with dollar pricing in trade. The former has disinflationary bias, while the latter has expansionary bias. When the intratemporal elasticity of substitution between home and foreign final goods is not equivalent to that between home and foreign intermediate goods, the two biases are not counterbalanced. Either way will lead to currency misalignment, ending in the inefficient price dispersion of identical goods across borders. Such an effect occurs regardless of the genre of trade links and has reinstated a strong case for international monetary policy coordination.

Keywords: Optimal monetary policy coordination; Production fragmentation; Vertical specialisation; Currency misalignment

JEL classification: F41; F42; F44

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1. INTRODUCTION

This paper proposes two novel views of optimal monetary policy coordination for open economies that are linked vertically and sequentially through production fragmentation across borders. First, we bring the variety of potential gains from international monetary policy coordination across the different types of trade linkages into limelight. Through the lens of a medium-scale New Keynesian model expanded with vertical specialisation, as developed in Wong and Eng (2013), we find that aggregate welfare gains from policy coordination can be as sizeable as 6% of steady-state consumption when the member economies vertically specialise along different chains of production. Nonetheless, self-oriented monetary policy is optimal for open economies that specialise in downstream production.

This finding goes beyond the traditional analysis of the interaction between trade openness in the aggregate sense and international policy coordination. The classic Oudiz and Sachs (1984), for instance, argue that, thanks to a relatively small trade link, the gain from international policy coordination for OECD countries is negligible. The more recent Coenen, Lombardo, Smets, and Straub (2010), using the New Area-Wide Model (NAWM) calibrated on Euro Area and the United States, show that when trade openness is two-fold, gain from policy coordination between these two large economies can be as sizeable as 1% of steady-state consumption. The novelty of this study is that it takes one step further from the size of trade openness by probing the question of how bilateral production and trade linkages of different types can result in various optimality of policy coordination.

The second contribution of this paper is that it presents optimal monetary policy coordination as competing objectives of optimal input allocation and optimal consumption allocation due to production fragmentation with U.S dollar invoiced trade when the intratemporal elasticity of substitution between home and foreign final goods is not equivalent to that between home and foreign intermediate goods. With the capital share of imported intermediate inputs priced in U.S dollars, the central bank faces disinflationary bias due to the fact that nominal appreciation reduces the price of imported intermediate inputs and thus the overall real marginal cost of production. At the same time, because nominal depreciation can be passed through into larger local-currency denominated export profit, the central bank has expansionary bias *in* assisting exporters to reduce the dollar-invoiced export price for foreign market expansion without jeopardising the profit margin. For an elasticity of substitution between home and foreign intermediate inputs that is greater than that for final goods, disinflationary bias dominates expansionary bias, resulting in nominal appreciation, or vice versa.

The consequence of these competing objectives is that it creates currency misalignment. When there is currency misalignment, households in the home and foreign economy pay different prices for the same goods, implying that the law of one price has been violated. Such inefficient price dispersion across borders, while the real marginal cost remains identical, leads to a reduction in world welfare. Moreover, the key determinant is the asymmetric adjustment in the exchange rate due to U.S dollar pricing in network-driven trade. Home currency depreciation against the U.S dollar no longer implies an equivalent foreign currency appreciation against the U.S dollar, despite the assumption of complete exchange rate pass-through. Exchange-rate fluctuation becomes inefficient, as it may engineer cross-border price dispersion, unnecessarily unbalancing the relative world demand. Thus, the currency misalignment effect has reinstated the strong case for monetary policy coordination.

Overall, we have reconciled three main ideas in the literature regarding optimal monetary policy coordination. The paper first builds on the literature with respect to the role of trade openness in policy coordination (i.e., Oudiz and Sachs, 1984) and expands on it by inspecting how the nature of trade openness affects the optimality of policy coordination.

It then brings in the literature that views optimal monetary policy for open economies as a tradeoff between expansionary bias in the presence of monopolistic allocation and disinflationary bias due to terms-of-trade externality (i.e., Corsetti and Pesenti, 2001; Benigno, 2002). However, it sheds new light by putting the tradeoff in the context of optimal consumption allocation versus optimal input allocation in production sharing with the U.S dollar-invoiced trade. This novel view is closely related in spirit to Devereux and Engel's (2007) view of exchange rate policy as a tradeoff between smoothened real exchange rates for optimal consumption allocations and flexible nominal exchange rates to facilitate terms-of-trade adjustment in intermediate input trade.

Finally, the paper bridges the analysis to the more recent view of optimal monetary policy in that currency misalignment that leads to the inefficient price dispersion of identical goods across borders is possible (Engel, 2011). Such misalignment ends in demand imbalances across countries that reduce world welfare (Corsetti, Dedola, and Leduc 2009, 2011). Nonetheless, that differentiates our findings from the existing literature in terms of the underlying factors of currency misalignment is the production fragmentation and the U.S dollar pricing mechanism in trade.

The paper is organised as follows. Section 2 lays out the linearised model of production fragmentation and trade. In Section 3, we will take a look at the parameterisation and shock calibration of the model. In Section 4, we derive a quadratic approximation of the utility-based welfare criterion around the non-distorted steady state for welfare comparison over optimal Nash and coordinated monetary policies, which are further discussed in Section 5. The role of the intra- and intertemporal elasticity of substitution is discussed in Section 6. The concept of optimal monetary policy coordination as a tradeoff between competing objectives for expansionary-biased optimal consumption allocations and disinflationary-biased optimal input allocations, which results in currency misalignment, is also addressed. Conclusions are drawn in Section 7.

2. THE LINEARIZED MODEL OF PRODUCTION FRAGMENTATION & TRADE

The macroeconomic model of production fragmentation and trade is indeed a medium-scale, two-country Smets and Wouters's (2003) model (SW model thereafter) in essence. It features external habit formation in consumption, investment adjustment cost, nominal rigidities in price and wage, partial indexation in time-dependent price and wage setting to produce more realistic dynamics. However, the SW model, as Wong and Eng (2013) argue, is far from adequate as a model of the international business cycle, particularly in accounting for business cycle comovement between economies with vertical trade links.

We thus expand an otherwise standard two-country SW model to incorporate three processing chains: upstream, midstream and downstream production. By doing so, a good is produced in three sequential stages. Because the chains of production are fragmented across borders, both countries use imported inputs in midstream and downstream production, and some of the resulting outputs are to be exported as intermediate inputs and final goods. As a result, both countries provide added value during the production of goods. This model thus genuinely embraces the concept of production fragmentation and value-added trade as outlined in Koopman, Powers, Wang, and Wei (2010), Johnson and Noguera (2012), and Hummels, Ishii, and Yi (2001).

Because decisions made by home and foreign economic agents are analogous ex ante in a two-country model, the discussion is mainly focused on the home economy, unless otherwise stated. The baseline model is outlined in Wong and Eng (2013). In this paper, we describe the log-linearised version of the model that was put into actual use for estimation. All variables are log-linearised around the steady state, $\hat{x}_t = x_t - \bar{x}$. Note also that for variable x_{ij}, where $i \neq j$, i denotes the source country or origin of production, while j denotes destination of export. When $i = j$, we simplify the notation to x_i. For instance, domestic final output for home consumption is denoted as $C_{\hbar}$ whereas imported final output from foreign country is $C_{\mathfrak{f}\hbar}$.

Value added: The aggregate added value of the economy is given by

$$\mathbb{Y}_t = \left(\frac{\bar{c}}{\bar{\mathbb{Y}}}\right)\hat{c}_t + \left(\frac{\bar{\imath}}{\bar{\mathbb{Y}}}\right)\hat{\imath}_t + \left(\frac{\bar{\mathbb{T}}}{\bar{\mathbb{Y}}}\right)\widehat{\mathbb{T}}_t \qquad \textbf{(1)}$$

where c, i, and $\mathbb{T}$,respectively, denote consumption, investment, and trade balance, respectively. The mass continuum households indexed by i choose the path of consumption, domestic bonds B_t and foreign bonds B_t^* denominated in the U.S dollar to maximize the utility function, $U\left(= E_t\left\{\sum_{t=0}^{\infty}\beta^t \mathrm{u}_t^C\left[\frac{(C_t(i)-bC_{t-1})^{1-\sigma}}{1-\sigma} - \mathrm{u}_t^N\frac{(N_t(i))^{1+\chi}}{1+\chi}\right]\right\}\right)$ subject to the flow budget constraint $C_t + \left(\frac{S_{hd,t}}{P_t \mathrm{u}_t^S}\right)\left(\frac{B_t^*}{R_t^{us}}\right) + \frac{B_t}{P_t R_t} + K_t = W_t\ N_t\ + \Pi_t +$

$(1-\delta)K_{t-1}+\left(\frac{S_{hd,t}B_{t-1}^{*}+B_{t-1}}{P_t}\right)$. The resulting consumption Euler equation and uncovered interest rate parity condition (UIPC) read

$$\hat{c}_t=\left(\frac{1}{1+b}\right)\hat{c}_{t+1}+\left(\frac{b}{1+b}\right)\hat{c}_{t-1}-\sigma^{-1}\left(\frac{1-b}{1+b}\right)\left(r_t-r_t^n-E_t\pi_{t+1}+\mathrm{u}_t^C-\mathrm{u}_{t+1}^C\right) \qquad \textbf{(2)}$$

$$r_t=r_t^{us}+E_t\hat{s}_{hd,t+1}-\hat{s}_{hd,t}+\mathrm{u}_t^s \qquad \textbf{(3)}$$

where the natural rate of interest is derived as $r_t^n=\mathrm{u}_t^C+\sigma(\mathrm{u}_t^a+\mathrm{u}_t^I)$. u_t^C is the i.i.d. preference shock, u_t^a and u_t^I are the i.i.d. innovation to the first-order autoregressive total factor production (TFP) and investment-specific technology (IST) shock with ρ_a and ρ_I measures the shock persistence, respectively, and u_t^s is the i.i.d. UIPC shock. $\hat{s}_{hd,t}$ indicates nominal exchange rate between home currency and the U.S. dollar, and lastly r_t and r_t^{us} denote domestic and U.S. interest rate, respectively.

The parameter b measures the degree of external habit formation. When $b=0$, a purely forward-looking consumption behaviour is obtained. The reciprocal of the parameter σ measures the intertemporal elasticity of the substitution of consumption. For $\sigma<1$ (elastic intertemporal substitution), the substitution effect of a higher real wage on employment dominates the negative wealth effect on the marginal utility of consumption, leading to a rise in hours worked following higher real wages. In other words, consumption and leisure are substitutes in utility.

The consumption bundle consists of home $\hat{c}_{\hbar,t}$ and imported final goods $\hat{c}_{f\hbar,t}\left(=\hat{y}_{3f\hbar,t}+\hat{\tau}_t\right)$, whose optimal demand schedules can be derived, respectively, as

$$\hat{c}_{\hbar,t}=\hat{c}_t+\varphi(1-\gamma)(\widehat{tot}_t) \qquad \textbf{(4)}$$

$$\hat{y}_{3f\hbar,t}=\hat{c}_t-\varphi\gamma(\widehat{tot}_t)-\hat{\tau}_t \qquad \textbf{(5)}$$

where $\widehat{tot}_{3,t}\left(=\eta\hat{s}_{hd,t}+\hat{p}_{3f\hbar,t}^{D}-\hat{p}_{3\hbar,t}\right)$ refers to terms of trade for final goods, defined in terms of the ratio between import price denominated in local currency and domestic price with $0 < \eta \leq 1$ indicates exchange rate pass-through into import price. Note that imports are invoiced in the U.S dollar. This is in line with the available evidence that finds U.S dollar as the dominant invoicing currency (see, for instance, Goldberg and Tille 2008). The parameter $\varphi > 1$ measures the elasticity of substitution between home and imported final goods, and γ indicates the degree of home bias.

Denoting $\widehat{m}_{n\mathscr{f}\mathscr{h},t}$ for $n = 1,2$ and $\hat{c}_{\mathscr{f}\mathscr{h},t}$ as the home c.i.f imports of upstream, midstream and final goods whereas $\hat{y}_{n\mathscr{f}\mathscr{h},t}$ as foreign f.o.b exports, transportation cost $\hat{\tau}_t$ is captured in the discrepancy between home c.i.f. imports and foreign f.o.b. exports (Ravn and Mazzenga, 2004). We assume for simplicity that transportation costs are synchronised across types of trade. Hence, the dynamics of trade balance becomes straightforward: they gauge the difference between total f.o.b. exports and total c.i.f. imports, $\widehat{\mathbb{T}}_t = \left(\frac{\overline{ex}}{\overline{\mathbb{T}}}\right)\widehat{ex}_t - \left(\frac{\overline{\imath m}}{\overline{\mathbb{T}}}\right)\widehat{\imath m}_t$, comprising trade in intermediates and final goods as follows:

$$\widehat{ex}_t = \left(\frac{\bar{y}_{1\mathscr{h}\mathscr{f}}}{\overline{ex}}\right)\hat{y}_{1\mathscr{h}\mathscr{f},t} + \left(\frac{\bar{y}_{2\mathscr{h}\mathscr{f}}}{\overline{ex}}\right)\hat{y}_{2\mathscr{h}\mathscr{f},t} + \left(\frac{\bar{y}_{3\mathscr{h}\mathscr{f}}}{\overline{ex}}\right)\hat{y}_{3\mathscr{h}\mathscr{f},t} \quad \textbf{(6)}$$

$$\widehat{\imath m}_t = \left(\frac{\overline{m}_{1\mathscr{f}\mathscr{h}}}{\overline{\imath m}}\right)\hat{y}_{1\mathscr{f}\mathscr{h},t} + \left(\frac{\overline{m}_{2\mathscr{f}\mathscr{h}}}{\overline{\imath m}}\right)\hat{y}_{2\mathscr{f}\mathscr{h},t} + \left(\frac{\bar{c}_{\mathscr{f}\mathscr{h}}}{\overline{\imath m}}\right)\hat{y}_{3\mathscr{f}\mathscr{h},t} + \hat{\tau}_t \quad \textbf{(7)}$$

Nominal wage setting: We assume that nominal wage is reappraised according to workers' performance. Generally, there are three categories of performance: "outperforming", "meet expectation", and "underperforming". In every time interval, the "outperforming" fraction of households $1 - \theta_w$ is rewarded with compensation that matches the welfare-maximizing wage level. Another fraction of households that achieves the "meet expectation" performance $\theta_w \gamma_w$ will receive compensation adjusted only for cost of living. The remaining "underperforming" fraction of households $\theta_w(1 - \gamma_w)$ will receive no wage adjustment in any form. Because the performance assessment normally takes place when a certain time interval has elapsed, it is thus not inappropriate to assume a time-dependent wage-setting mechanism. The nominal wage inflation can be derived as follows:

$$\pi_{w,t} = \left\{\frac{\gamma_w}{1+\beta\gamma_w\theta_w}\right\}\pi_{w,t-1} + \left\{\frac{\beta}{1+\beta\gamma_w\theta_w}\right\}E_t\pi_{w,t+1} + \left\{\frac{(1-\theta_w)(1-\theta_w\beta)}{\theta_w(1+\beta\gamma_w\theta_w)}\right\}(\mathcal{w}_t + \mathrm{u}_t^W) \quad \textbf{(8)}$$

where $\mathcal{w}_t = \widehat{w}_t^{MRS} - \widehat{w}_t$. u_t^W is the i.i.d wage markup shock. $\widehat{w}_t^{MRS}$ refers the welfare-maximizing wage that equilibrates the marginal utility of consumption and marginal disutility of work

$$\widehat{w}_t^{MRS} = \chi\hat{n}_t + \left(\frac{\sigma}{1-b}\right)(\hat{c}_t - b\hat{c}_{t-1}) + \mathrm{u}_t^N \quad \textbf{(9)}$$

where χ denotes the reciprocal of wage elasticity of labour supply and u_t^N is the i.i.d. labour supply shock.

Chains of production: International trade in intermediates and final goods is indeed the corollary of production fragmentation across borders. Consider that a perfectly competitive upstream firm accumulates capital stock and, in conjunction with labourer services in Cobb-Douglas fashion, produces plant-specific output

$$\hat{y}_{1t}(j) = \hat{a}_t + \alpha\hat{k}_{t-1}(j) + (1-\alpha)\hat{n}_t(j) \quad \textbf{(10)}$$

where the total factor productivity (TFP) shock, $\hat{a}_t$, follows a first-order autoregressive process. By minimising the expenditure of production subject to the production net of the investment adjustment cost, $S(I_t(j)/I_{t-1}(j))$, the investment dynamics can bederived as follows

$$\hat{\iota}_t = \left(\frac{1-\mathfrak{F}}{2-\mathfrak{F}}\right)\hat{\iota}_{t-1} + \left(\frac{1}{2-\mathfrak{F}}\right)E_t\hat{\iota}_{t+1} + \left(\frac{1-\mathfrak{F}}{2-\mathfrak{F}}\right)\left\{\begin{matrix}\left(\frac{1+\mathfrak{F}}{2}\right)E_t\{\alpha r_{K,t+1} + (1-\alpha)\widehat{w}_{t+1} - \hat{a}_{t+1}\} \\ -\alpha r_{K,t} - (1-\alpha)\widehat{w}_t + \hat{a}_t\end{matrix}\right\}$$

$$+\left(\frac{1-\mathfrak{F}}{2-\mathfrak{F}}\right)(\hat{e}^I_{t-1}-\hat{e}^I_t)+\left(\frac{1}{2-\mathfrak{F}}\right)E_t\hat{e}^I_{t+1} \quad \textbf{(11)}$$

where the parameter $\mathfrak{F}$ scales the relative importance between forward- and backward-looking investment dynamics, $r_{K,t}$ denotes the real return on capital stock, $\widehat{w}_t$ the real compensation to labour services, and $\hat{e}^I_t$ is the AR(1) investment-specific technology (IST) shock. The law of motion of capital accumulation is given by

$$\hat{k}_t=(1-\delta)\hat{k}_{t-1}+\delta(\hat{\imath}_t+\hat{e}^I_t)+\frac{\Psi}{2}\left(\frac{\delta(1-\aleph)^2}{1-\frac{\Psi}{2}(1-\aleph)^2}\right)(\hat{\imath}_t-\hat{\imath}_{t-1}+\hat{e}^I_t-\hat{e}^I_{t-1}) \quad \textbf{(12)}$$

The parameters Ψ and δdenote the adjustment cost and depreciation rate, respectively.

Moving further down the value chains, a continuum of monopolistically competitive midstream producers, indexed by $j\in J$, will import and combine foreign upstream intermediates with the local one at constant elasticity of substitution (CES) for further processing. So does the home monopolistically competitive downstream firm $j\epsilon J$ that manufactures local intermediate inputs together with the imported intermediates in CES technology to produce final output.

By optimising the use of domestic and imported intermediates to minimise the production expenditure subject to the CES production constraint, optimal demand for home and imported upstream as well as midstream intermediates, which depends on the scale of $\hat{y}_{n,t}$ and terms of trade $\widehat{tot}_{n,t}$ for $n=1,2$ are of the form

$$\hat{y}_{n\hbar,t}=\hat{y}_{n+1,t}+\vartheta\kappa_{n+1}\left(\widehat{tot}_{n,t}\right) \quad \textbf{(13)}$$

$$\hat{y}_{n\not{f}\hbar,t}=\hat{y}_{n+1,t}-\vartheta(1-\kappa_{n+1})\left(\widehat{tot}_{n,t}\right)-\hat{\tau}_t \quad \textbf{(14)}$$

where the parameters κ_2 and $\vartheta>0$ denote the share of imported intermediates in production and the elasticity of substitution between home and imported intermediates, respectively. It can be seen that demand for intermediates produced at upper stream is proportional to the scale of production, and can be reshuffled in responding to movement in terms of trade.

When value chains are sliced up and fragmented across borders, the processed output of each chain will certainly move across borders and become the input for subsequent chain of production. It follows that the market clearing conditions for upstream and midstream output, respectively, are given by

$$\hat{y}_{1t} = \left(\frac{\bar{y}_{1\hbar}}{\bar{y}_1}\right)\hat{y}_{1\hbar,t} + \left(\frac{\bar{y}_{1\hbar\not{f}}}{\bar{y}_1}\right)\hat{y}_{1\hbar\not{f},t} \quad \mathbf{(15)}$$

$$\hat{y}_{2t} = \left(\frac{\bar{y}_{2\hbar}}{\bar{y}_2}\right)\hat{y}_{2\hbar,t} + \left(\frac{\bar{y}_{2\hbar\not{f}}}{\bar{y}_1}\right)\hat{y}_{2\hbar\not{f},t} \quad \mathbf{(16)}$$

More interesting is the market clearing condition for final goods in that the output can be consumed by domestic households, exported for foreign households' consumption, or reinvested as capital stock by home upstream firms:

$$\hat{y}_{3t} = \left(\frac{\bar{c}_{\hbar}}{\bar{y}_3}\right)\hat{c}_{\hbar,t} + \left(\frac{\bar{y}_{3\hbar\not{f}}}{\bar{y}_3}\right)\hat{y}_{3\hbar\not{f},t} + \left(\frac{\bar{\imath}}{\bar{y}_3}\right)\hat{\imath}_t \quad \mathbf{(17)}$$

When re-invested final goods materialise as the capital inputs for upstream production, of which the output will be used as intermediates for midstream processing, a model of production fragmentation with simple "intermediate loops" is established. It is also worthwhile to point out that despite the parsimonious modelling on fragmentation in production and trade, the resulting gross trade is able to be decomposed into value added components compatible with the most comprehensive definition of value-added trade in the empirical trade literature (see Wong and Eng, 2012b).

Time-dependent U.S dollar pricing: The midstream and downstream firms have to make pricing decisions. Suppose $\mathbb{P}_{n\hbar,t}$ and $\mathbb{P}^{D}_{n\hbar\not{f},t}$ are the optimal reset prices that maximise the expected discounted profits denominated in local currency for sales in the home and export market, respectively. Those who are signalled for price re-optimisation at $1-\theta_{n\hbar}$probability ($1-\theta_{n\hbar f}$ for exporters), for $n=2,3$, will choose $\widehat{\mathbb{P}}^{new}_{n\hbar,t}\left(\widehat{\mathbb{P}}^{new}_{n\hbar f,t}\right)$ to approximate the optimal reset price. The remaining firms that do not receive the signal for price re-optimisation will adhere to the last-period price, out of which a fraction $\gamma^{p}_{n\hbar}\left(\gamma^{p}_{n\hbar f}\right)$ will be indexed to the last-period inflation. Inflation dynamics for producer price (PPI) $\pi_{2\hbar,t}$, GDP deflator $\pi_{3\hbar,t}$, intermediate export price $\pi_{2\hbar f,t}$, and final export price $\pi_{3\hbar f,t}$ can be derived as

$$\pi_{n\hbar,t}=\left(\frac{\gamma_{Pn}}{1+\theta_{n\hbar}\beta\gamma^{p}_{n\hbar}}\right)\pi_{n\hbar,t-1}+\left(\frac{\beta}{1+\theta_{n\hbar}\beta\gamma^{p}_{n\hbar}}\right)E_t\pi_{n\hbar,t+1}+\lambda_{n\hbar}\left(\widehat{rmc}_{n,t}+\mathrm{u}^{p}_{n\hbar,t}\right) \quad \textbf{(18)}$$

$$\pi_{n\hbar f,t}=\left(\frac{\gamma^{p}_{n\hbar f}}{1+\theta_{n\hbar f}\beta\gamma^{p}_{n\hbar f}}\right)\pi_{n\hbar f,t-1}+\left(\frac{\beta}{1+\theta_{n\hbar f}\beta\gamma^{p}_{n\hbar f}}\right)E_t\pi_{n\hbar f,t+1}$$
$$+\lambda_{n\hbar f}\left(\widehat{rmc}_{n,t}-\hat{s}_{hd,t}+\mathrm{u}^{p}_{n\hbar f,t}\right) \quad \textbf{(19)}$$

where

$\lambda_{n\hbar}=\frac{(1-\theta_{n\hbar})(1-\theta_{n\hbar}\beta)}{\theta_{n\hbar}(1+\theta_{n\hbar}\beta\gamma^{p}_{n\hbar})}and\lambda_{n\hbar f}=\frac{(1-\theta_{n\hbar f})(1-\theta_{n\hbar f}\beta)}{\theta_{n\hbar f}\left(1+\theta_{n\hbar f}\beta\gamma^{p}_{n\hbar f}\right)}$. $\mathrm{u}^{p}_{n\hbar,t}$ and $\mathrm{u}^{p}_{n\hbar f,t}$ are i.i.d. home and export price markup shock for $n=2,3$, respectively. $\widehat{rmc}_{2,t}\left(=\hat{p}_{1,t}\right)$ is the real marginal cost of midstream producers, consisting of the weighted flexible prices of outputs sourced from home and foreign upstream producers, $\hat{p}_{1,t}=\hat{p}_{1\hbar,t}+\kappa_2\left(\eta\hat{s}_{hd,t}+\hat{p}^{D}_{1f\hbar,t}-\hat{p}_{1\hbar,t}\right)$. In a perfectly competitive upstream market, price is flexible and approximates the marginal cost. As such, we obtain $\hat{p}_{1\hbar,t}=\alpha r_{K,t}+(1-\alpha)\widehat{w}_t-\hat{a}_t$. Meanwhile, $\widehat{rmc}_{3,t}\left(=\hat{p}_{2,t}\right)$ is the real marginal cost of downstream producers, which is composed of the weighted sticky producer price of intermediate inputs sourced from home and foreign midstream producers, $\hat{p}_{2,t}=\hat{p}_{2\hbar,t}+\kappa_3\left(\eta\hat{s}_t+\hat{p}^{D}_{2f,t}-\hat{p}_{2\hbar,t}\right)$. Under time-dependent pricing mechanism, only a fraction of midstream producers is able to reset the price to approximate the marginal cost. As a consequence, $\hat{p}_{2\hbar,t} = \theta_{2\hbar}\left(\hat{p}_{2\hbar,t-1} + \gamma^{p}_{2\hbar}\pi_{2\hbar,t-1}\right) + (1-\theta_{2\hbar})\left(\widehat{rmc}_{2,t}\right)$. Finally, given the terms of trade for multiple stages of production as defined earlier, "aggregate" terms of trade weighted by export share is given by

$$\widehat{tot}^{a}_{t} = \eta\hat{s}_t + \sum_{n=1}^{3}\left(\frac{\bar{y}_{n\hbar\not f}}{\overline{ex}}\right)\left(\hat{p}^{D}_{n\not f,t} - \hat{p}_{n\hbar,t}\right) \qquad \textbf{(20)}$$

Exchange rate pass-through under dollar pricing: The dollar pricing mechanism with vertical production linkage interestingly allows the coexistence of three seemingly contradictory characteristics: rapid exchange rate pass-through into import price, low pass-through into output price, and non-zero pass-through into export price. By assuming a complete exchange rate pass-through into import price, nominal depreciation, as the argument goes, raises the unit import price in the local currency. Terms of trade, defined as the ratio between import and domestic price in local currency, thus still comove closely with nominal exchange rates as shown in Eq. (20).

Because of the sequential chains of productions, exchange rate pass-through into output price is unsurprisingly low even when exchange rate pass-through into price of imported intermediates is complete. A depreciation that increases the domestic price of imported upstream goods will only be passed through into the real marginal cost of midstream firms by κ_2 and thus midstream output price by $\lambda_{2\hbar}\kappa_2$. When moving downstream, the pass-through is further reduced to $\lambda_{2\hbar}\kappa_2\lambda_{3\hbar}(1-\kappa_3)$. Combined with the pass-through of higher imported midstream output price by $\lambda_{3\hbar}\kappa_3$, total exchange rate pass-through into final output price is $\lambda_{3\hbar}\{\kappa_3 + \lambda_{2\hbar}\kappa_2(1-\kappa_3)\}$.Suppose price is re-optimized in every 4 quarters $(\theta = 0.75)$ with no indexation, discount rate is 6% per annum, and the share of imported intermediates in both midstream and downstream production is as high as 90%. A 10% nominal depreciation causes a rise in output price by 0.8% at most. Last but not least, given the dollar price of export, nominal depreciation raises the export revenue denominated in local currency. The expanded export revenue actually enables exporters to reduce the export price without jeopardizing the profit margin, as shown in Eq. (19), which helps to bolster the foreign demand for exports. In other words, unlike buyer's currency pricing, dollar pricing still instigates expenditure-switching effect although the exports are not invoiced in home currency.

A Measure of country upstreamness: By decomposing gross exports into domestic and foreign value added, we can construct a simple index that helps us to trace the upstreamness of a country within the global production sharing chain. Intuitively, the intermediate exports of countries engaged in upstream of the production sharing are more likely to be shipped back home for further processing as compared with countries occupying downstream production. In consequence, reflected domestic value added in the gross exports of upstream countries will be more than proportionate to the foreign value added in its gross exports.

In light of Wong and Eng (2012a) that draw upon Koopman et al.'s (2010) empirical decomposition of value added, the country upstreamness index is computed as the home country's log ratio of $VS1*$ to VS in gross exports.

$$U = ln\left(1 + \frac{VS1*}{\mathbb{x}_t}\right) - ln\left(1 + \frac{VS}{\mathbb{x}_t}\right) \quad \textbf{(21)}$$

where

$$VS1*_t = \left(1 - \frac{M_{0\not{f}\hbar,t}}{Y_{1t}}\right)\left(\frac{M_{1\hbar\not{f},t}}{Y^f_{2t}}\right)Y_{2\not{f}\hbar,t} + \left(1 - \frac{M_{1\not{f}\hbar,t}}{Y_{2t}}\right)\left(\frac{M_{2\hbar\not{f},t}}{Y^f_{3t}}\right)Y_{3\not{f}\hbar,t} \quad \textbf{(22)}$$

$$VS_t = \left(1 - \frac{M_{0\hbar\not{f},t}}{Y^f_{1t}}\right)\left(\frac{M_{1\not{f}\hbar,t}}{Y_{2t}}\right)Y_{2\hbar\not{f},t} + \left(1 - \frac{M_{1\hbar\not{f},t}}{Y^f_{2t}}\right)\left(\frac{M_{2\not{f}\hbar,t}}{Y_{3t}}\right)Y_{3\hbar\not{f},t} \quad \textbf{(23)}$$

$VS1*$ (22), known as "reflected domestic value added", consists of domestic value added embodies in the domestic intermediates used in foreign production for re-exporting back to the source as intermediates or final goods. Note that foreign value added incorporated at an earlier stage of production of domestic intermediates has to be taken into account. VS (23) refers to the foreign content of domestic exports, after accounting for the domestic value added embodied in foreign intermediates. This is usually taken as the simple form of vertical specialization.

3. PARAMETERISATION AND CALIBRATION

This section lays out the values of the parameters and shock innovation used for policy simulation. The model is calibrated on the New Keynesian model of production fragmentation estimated in Wong and Eng (2012b) based on 19 trade-weighted macroeconomic time series on advanced East Asian economies (which include Japan, Korea, Hong Kong, Taiwan, and Singapore), developing Southeast Asian economies (which include Indonesia, Malaysia, the Philippines, and Thailand), and China over the period from 2001Q1 to 2008Q4 using Bayesian approach. Altogether, two two-country models have been estimated, namely China-East Asian economies and China-Southeast Asian economies.

Table 1 reports the values of the selected parameters and shocks. There are several interesting features. For instance, the intertemporal elasticity of substitution takes different values for different bilateral interactions; the advanced East Asian countries are relatively “closed” in the final goods market compared with the developing Southeast Asian countries, given the much higher home biasness in consumption; investment is very forward-looking; Southeast Asia has a stronger production link with East Asia in midstream production, while production in East Asia is coupled more tightly with Southeast Asia in downstream processing; the price of final goods in the local market is more rigid vis-à-vis producer prices in the local market and final goods prices in the export market; and inefficient price markup shocks are generally more volatile than the efficient TFP shock, IST shock, and preference shock.

[INSERT TABLE 1 HERE]

That said, we do not intend to frame the discussion in Asian context. Instead, based on the position of each country in regional value chains of production identified by Wong and Eng (2012a, 2012b), we generalise the estimates on advanced East Asia-China model and China-developing Southeast Asia model into upstream-downstream (U-D) model and upper downstream-lower downstream (D-D) model, respectively. This classification allows us to study how the welfare cost of non-coordination may vary across the bilateral production linkages.

4. CHARACTERISING THE WELFARE CRITERION

In this section, we provide an illustration of the welfare loss function derived from the model of production fragmentation and trade. The loss function interestingly encompasses those obtained in the standard New Keynesian closed-economy model (Gali, 2008), in the closed-economy model with a roundabout input-output structure (Petrella and Santoro, 2011), and the open-economy model with trade in final goods only (Gali and Monacelli, 2005). Following the tradition of New Keynesian literature as in Woodford (2003) and Gali (2008), we derive a quadratic approximation of the utility-based welfare criterion around the non-distorted steady state by taking into account all of the resource constraints. Through the procedure detailed in the appendix, we can obtain the following welfare loss function

$$\mathbb{W} = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{U_t - U}{U_c c}\right)$$

of which

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{U_t - U}{U_c c}\right)$$

$$= \left\{\frac{\overline{\mathbb{Y}}}{\bar{c}} . \widehat{\mathbb{Y}}_t + \Gamma_c \hat{\mathcal{G}}_t^c + \Gamma_i \hat{\mathcal{G}}_t^i + (\Gamma_{tot} - \Gamma_{tot^*}) \widehat{tot}_t + \Gamma_{tot^*} \hat{\mathcal{G}}_t^{tot} + \Gamma_\tau \hat{\tau}_t + \Gamma_{\tau^*} \hat{\tau}_t^* - \frac{\bar{y}_1}{\bar{c}} \hat{y}_t^{\mathcal{G}}\right\}$$

$$+ \left(\frac{\bar{c}}{\overline{\overline{\mathbb{Y}}}}\right)^{-1} \left(\frac{\varepsilon}{2\lambda_{3h}}\right) (\pi_{3h,t})^2 + \frac{\overline{im}}{\bar{c}} (\pi_{fh,t})^2 - \frac{\overline{ex}}{\bar{c}} (\pi_{hf,t})^2$$

$$- \left(\frac{\sigma - 1}{2}\right) \left\{ \left(\frac{\bar{c}}{\overline{\overline{\mathbb{Y}}}}\right)^{-2} (\widehat{\mathbb{Y}}_t)^2 + \left(\Gamma_c \hat{\mathcal{G}}_t^c\right)^2 + \left(\Gamma_i \hat{\mathcal{G}}_t^i\right)^2 + \left((\Gamma_{tot} - \Gamma_{tot^*}) \widehat{tot}_t\right)^2 \right.$$

$$\left. + \left(\Gamma_{tot^*} \hat{\mathcal{G}}_t^{tot}\right)^2 + (\Gamma_\tau \hat{\tau}_t)^2 + (\Gamma_{\tau^*} \hat{\tau}_t^*)^2 \right\}$$

$$- \frac{\bar{y}_1}{\bar{c}} \left\{ (\varepsilon_w (1 + \chi) + 1)(1 - \alpha) \left(\frac{\varepsilon_w}{2\lambda_w}\right) (\pi_{w,t})^2 + \frac{1 + \chi}{2} \left(\hat{y}_t^{\mathcal{G}}\right)^2 \right\}$$

$$+ t.i.p + O(\|\zeta\|^3) \qquad \textbf{(24)}$$

where $\hat{\mathcal{G}}_t^c \left(= \hat{c}_t - \frac{\Gamma_c^*}{\Gamma_c} \hat{c}_t^*\right)$ and $\hat{\mathcal{G}}_t^i \left(= \hat{\imath}_t - \frac{\Gamma_{i^*}}{\Gamma_i} \hat{\imath}_t^*\right)$ refer to consumption imbalance and investment imbalance, respectively. As we shall see later, given the calibrated Γ_i and Γ_i^* that are closed to zero, special attention is devoted to consumption imbalance that resembles in spirit Corsetti et al.'s (2010) demand imbalances. $\hat{\mathcal{G}}_t^{tot}\big(= (\eta^* - 1)\hat{s}_{fd,t} - (\eta - 1)\hat{s}_{hd,t}\big)$ is known as terms-of-trade gap between foreign and home nations. When exchange rate pass-through into both foreign and home import price are zero, domestic terms of trade are exactly the reciprocal of foreign terms of trade. There exists gap whenever $\eta^*, \eta \neq 1$. $\pi_{fh,t} \left(= \left(\frac{\bar{m}_{1fh}}{\overline{im}}\right)\left(\frac{\varepsilon}{\lambda_{1fh}}\right)(\pi_{1fh,t})^2 + \left(\frac{\bar{m}_{2fh}}{\overline{im}}\right)\left(\frac{\varepsilon}{\lambda_{2fh}}\right)(\pi_{2fh,t})^2 + \left(\frac{\bar{c}_{fh}}{\overline{im}}\right)\left(\frac{\varepsilon}{\lambda_{3fh}}\right)(\pi_{3fh,t})^2\right)$ is the average import price inflation, whereas $\pi_{hf,t} \Big(=$

$\left(\frac{\bar{y}_{1\hbar f}}{\overline{ex}}\right)\left(\frac{\varepsilon}{\lambda_{1\hbar f}}\right)\left(\pi_{1\hbar f,t}\right)^2+\left(\frac{\bar{y}_{2\hbar f}}{\overline{ex}}\right)\left(\frac{\varepsilon}{\lambda_{2\hbar f}}\right)\left(\pi_{2\hbar f,t}\right)^2+\left(\frac{\bar{y}_{3\hbar f}}{\overline{ex}}\right)\left(\frac{\varepsilon}{\lambda_{3\hbar f}}\right)\left(\pi_{3\hbar f,t}\right)^2\Big)$ is the average export price inflation across chains of production, weighted by respective share in gross exports and imports. Lastly, by loosely defining $\tilde{y}_t^p\left(=\hat{a}_t+\alpha\hat{k}_{t-1}\right)$ as the potential output, $\hat{y}_t^{\mathcal{G}}\left(=\tilde{y}_{1t}-\tilde{y}_t^p\right)$ approximates the output gap. The term $t.i.p$ denotes the terms independent of policy, and $O(\|\zeta\|^3)$ refers to the residuals of order three. Table 2 defines the parameters in welfare criterion (24).

[INSERT TABLE 2 HERE]

The first row of the right-hand side of Eq. (24) collects all the first moments of the variables. In a closed-economy framework, the first moments are usually eliminated by a production subsidy (Woodford, 2003). One problem with such an approach that eliminates monopolistic distortion is that it renders the search for optimal monetary policy in an economic environment inhabited by price setters due to the presence of monopolistic competition meaningless (see Tchakarov, 2004). Benigno and Benigno (2003) argue that the co-existence of inflationary bias due to the presence of monopolistic competition and deflationary bias triggered by an improvement in terms of trade is essential for price stability in open economies.

Our method of eliminating the first-order terms in the welfare loss function is conceptually straightforward. Welfare is maximised when the macroeconomic volatilities are eliminated. Simply put, the maximised welfare is obtained when all the variances are zero.

$$\mathbb{W}^M=\left(\frac{\bar{C}}{\bar{\bar{\mathbb{Y}}}}\right)^{-1}\hat{\mathbb{Y}}_t+\Gamma_c\hat{\mathcal{G}}_t^c+\Gamma_i\hat{\mathcal{G}}_t^i+\left(\Gamma_{tot}-\Gamma_{tot^*}\right)\widehat{tot}_t+\Gamma_{tot^*}\hat{\mathcal{G}}_t^{tot}+\Gamma_\tau\hat{\tau}_t+\Gamma_{\tau^*}\hat{\tau}_t^*$$

By inspecting the unconditional welfare measure around the *maximised state of welfare*, we can easily eliminate the first-order terms, as shown in Eq. (25).

$$\widetilde{\mathbb{W}} = \mathbb{W} - \mathbb{W}^M$$

$$= \left(\frac{\bar{c}}{\bar{\bar{\mathbb{Y}}}}\right)^{-1} \left(\frac{\varepsilon}{2\lambda_{3\hbar}}\right) \left(\pi_{3\hbar,t}\right)^2 + \frac{\overline{im}}{\bar{c}} \left(\pi_{\text{ff}\hbar,t}\right)^2 - \frac{\overline{ex}}{\bar{c}} \left(\pi_{\hbar\text{f},t}\right)^2$$

$$- \left(\frac{\sigma - 1}{2}\right) \left\{ \left(\frac{\bar{c}}{\bar{\bar{\mathbb{Y}}}}\right)^{-2} \left(\widehat{\mathbb{Y}}_t\right)^2 + \left(\Gamma_c \hat{\mathcal{G}}_t^c\right)^2 + \left(\Gamma_i \hat{\mathcal{G}}_t^i\right)^2 + \left((\Gamma_{tot} - \Gamma_{tot^*})\widehat{tot}_t\right)^2 \right.$$

$$\left. + \left(\Gamma_{tot^*} \hat{\mathcal{G}}_t^{tot}\right)^2 + (\Gamma_\tau \hat{\tau}_t)^2 + (\Gamma_{\tau^*} \hat{\tau}_t^*)^2 \right\}$$

$$- \frac{\bar{y}_1}{\bar{c}} \left\{ (\varepsilon_w (1 + \chi) + 1)(1 - \alpha) \left(\frac{\varepsilon_w}{2\lambda_w}\right) \left(\pi_{w,t}\right)^2 + \frac{1 + \chi}{2} \left(\hat{y}_t^{\mathcal{G}}\right)^2 \right\}$$

$$+ t.i.p + O(\|\zeta\|^3) \qquad \textbf{(25)}$$

Eq. (25) bears a familiar resemblance to the welfare measure for both closed and open economies. For a closed economy with unitary intra- and intertemporal elasticity of substitution, Eq. (25) boils down to

$$\widetilde{\mathbb{W}} = \left(\frac{\bar{c}}{\bar{\bar{\mathbb{Y}}}}\right)^{-1} \left(\frac{\varepsilon}{2\lambda_{3\hbar}}\right) \left(\pi_{3\hbar,t}\right)^2 - \frac{\bar{y}_1}{\bar{c}} \left\{ (\varepsilon_w (1 + \chi) + 1)(1 - \alpha) \left(\frac{\varepsilon_w}{2\lambda_w}\right) \left(\pi_{w,t}\right)^2 + \right.$$

$$\left. \frac{1+\chi}{2} \left(\hat{y}_t^{\mathcal{G}}\right)^2 \right\} + t.i.p + O(\|\zeta\|^3) \qquad \textbf{(26)}$$

Eq. (26) principally argues that the central bank stabilises domestic inflation, nominal wage inflation, and output gap (Erceg et al., 2000; Gali, 2008).For the more general case in which $\sigma \neq 1$, Eq. (25) becomes

$$\widetilde{\mathbb{W}} = \left(\frac{\bar{c}}{\bar{\bar{\mathbb{Y}}}}\right)^{-1} \left(\frac{\varepsilon}{2\lambda_{3\hbar}}\right) \left(\pi_{3\hbar,t}\right)^2 - \left(\frac{\sigma - 1}{2}\right) \left(\frac{\bar{c}}{\bar{\bar{\mathbb{Y}}}}\right)^{-2} \left(\widehat{\mathbb{Y}}_t\right)^2$$

$$- \frac{\bar{y}_1}{\bar{c}} \left\{ (\varepsilon_w (1 + \chi) + 1)(1 - \alpha) \left(\frac{\varepsilon_w}{2\lambda_w}\right) \left(\pi_{w,t}\right)^2 + \frac{1 + \chi}{2} \left(\hat{y}_t^{\mathcal{G}}\right)^2 \right\}$$

$$+ t.i.p + O(\|\zeta\|^3) \qquad \textbf{(27)}$$

The distinction between value added and gross output becomes clear when a more realistic input-output structure is considered. This is in line with findings in Petrella and

Santoro's (2011) who use a two-sector model that features an effectively infinite input-output loop when the final output is allowed to serve as intermediate inputs in both sectors, whose optimal monetary policy for a model economy with roundabout production moderates inflation and value added not output gap variability. Targeting gross output variability entails a substantial loss in welfare.

What differentiate Eq. (27) from Petrella and Santoro (2011) is the role of intertemporal elasticity of substitution in conjunction with the relative degrees of forward-looking behaviour in consumption and investment. Consider, for instance, a favourable TFP shock that leads to negative output gap and raises the natural rate of interest. A higher natural rate stimulates current consumption, and the resulting lower marginal utility prompts a rise in wages. Thus, while TFP has a direct positive effect on investment dynamics, the increase in wages takes a toll on private investment. The net effect on value added depends on the value of σ.

When $\sigma < 1$, wages rises to a smaller extent, implying that the effect of TFP shock on investment remains positive in balance. As a result, the value added increases, contributing to the rising demand for upstream output through an input-output structure. The negative output gap is thus closed. As such, the optimal policy response leans with the wind of value added variability. By contrast, for $\sigma > 1$, investment decreases due to the dominance of the adverse wage effect over the direct positive effect of TFP shock, contributing to a contraction in value added. The negative output gap worsens as the demand for upstream output collapses. The optimal policy thus requires the central bank to counter against the value added variability.

The implications become even more fascinating once the fact that upstream and midstream outputs are also tradable is taken into account. As shown in Eq. (25), the benevolent policymakers for open economies with production fragmentation pay attention to the inflation variability in domestic and export markets for both intermediate and final consumption goods; they respond to the variability in the imported and exported intermediate inputs price inflation; depending on the value of σ, they are concerned with consumption and investment imbalances; and they react to the terms-of-trade gap and variability.

5. OPTIMAL NASH AND COORDINATED MONETARY POLICY

For welfare comparison, we consider two policy regimes:

Nash policy regime (NPR): home central bank stabilizes only domestic variables, taking as given the entire path of foreign monetary policy instrument. This is clearly an open-loop Nash optimal monetary policy (See Coenen et al., 2000 for discussion on the different types of optimal Nash monetary policy). The optimized policy rule maximizing the welfare loss function (25) is given by

$$r_t = \omega_{\pi_{3\hbar}} \pi_{3\hbar,t} + \omega_{\pi_{\mathfrak{f}\hbar}} \pi_{\mathfrak{f}\hbar,t} + \omega_{\pi_{\hbar\mathfrak{f}}} \pi_{\hbar\mathfrak{f},t} + \omega_{\mathbb{Y}} \widehat{\mathbb{Y}}_t + \omega_{\mathcal{G}^c} \hat{\mathcal{G}}_t^c + \omega_{\mathcal{G}^i} \hat{\mathcal{G}}_t^i + \omega_{tot} \widehat{tot}_t + \omega_{\mathcal{G}^{tot}} \hat{\mathcal{G}}_t^{tot} + \omega_\tau \hat{\tau}_t + \omega_{\tau^*} \hat{\tau}_t^* + \omega_{\pi_w} \pi_{w,t} + \omega_{y^{\mathcal{G}}} \hat{y}_t^{\mathcal{G}} \quad \textbf{(28)}$$

Coordinated policy regime (CPR): home and foreign central banks stabilize own domestic variables in the conduct of respective monetary policy according to Eq. (28) to maximize the joint welfare loss function

$$\widetilde{\mathbb{W}}^C = \rho \widetilde{\mathbb{W}} + (1 - \rho) \widetilde{\mathbb{W}}^* \quad \textbf{(29)}$$

where ρ refers to the weight given to home welfare loss function.

By setting Nash regime as the baseline, we first investigate its welfare performance when productions in both countries are linked vertically and sequentially, as well as when both countries specialise in identical stage of production. We carry out the same exercise for coordinated regime. We next compare the welfare gains in Nash regime with coordinated regime to quantify the welfare cost of non-coordination.

Deriving welfare cost of non-coordination: Denoting $\lambda^{\mathbb{W}}$ as the welfare cost of adopting Nash regime instead of the coordinated policy regime, $\lambda^{\mathbb{W}}$can be interpreted as the fraction of consumption process compensated for households' willingness to be free of coordination while still being as well off under Nash policy regime $U(C_t^{NP}, N_t^{NP})$as under the coordinated policy regime, $U(C_t^{CO}, N_t^{CO})$ given the level of leisure. Hence, we solve for $\lambda^{\mathbb{W}}$ such that

$$U(C_t^{CO}, N_t^{CO}) = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{(C_t^{CO})^{1-\sigma}}{1-\sigma} - \frac{(N_t^{CO})^{1+\chi}}{1+\chi} \right)$$

$$= E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{\left((1+\lambda^{\mathbb{W}})C_t^{NP}\right)^{1-\sigma}}{1-\sigma} - \frac{(N_t^{NP})^{1+\chi}}{1+\chi} \right)$$

$$= \{(1+\lambda^{\mathbb{W}})^{1-\sigma} - 1\} \times E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{\left(C_t^{NP}\right)^{1-\sigma}}{1-\sigma} \right) + U(C_t^{NP}, N_t^{NP})$$

$$= \{(1+\lambda^{\mathbb{W}})^{1-\sigma} - 1\} \times \frac{(C_t^{NP})^{1-\sigma}}{(1-\beta)(1-\sigma)} + U(C_t^{NP}, N_t^{NP})$$

which gives us

$$\lambda^{\mathbb{W}} = (1-\beta) \left(\frac{U(C_t^{CO}, N_t^{CO}) - U(C_t^{NP}, N_t^{NP})}{\left(C_t^{NP}\right)^{1-\sigma}} \right) = (1-\beta)(\mathbb{W}^{CO} - \mathbb{W}^{NP}) \qquad \textbf{(30)}$$

As $\mathbb{W}^{NP}, \mathbb{W}^{CO} \in \mathcal{R}^-$, there is welfare gain of non-coordination if $\lambda^{\mathbb{W}} > 0$ but welfare loss if $\lambda^{\mathbb{W}} < 0$. Table 3 reports the quantified value of the welfare loss function (25) based on the joint consideration of calibrated parameters and steady states (see Table 1) and definition of coefficients of each variable in the loss function (see Table 2). As investment imbalances, terms-of-trade gap, and domestic transportation cost plays no practical role in the calibrated welfare loss function, for subsequent simulation we assume that $\omega_{\mathcal{G}^i}, \omega_{\mathcal{G}^{tot}}, \omega_\tau = 0$.

[INSERT TABLE 3 HERE]

Baseline results: Table 4 depicts macroeconomic volatility measured in standard deviations and welfare loss under NPR, as well as the welfare cost of non-coordination over two different bilateral production linkages with different weights for home country in the joint welfare function. Note that home (foreign) nation refers to downstream (upstream) country in the upstream-downstream (U-D) model, whereas home nation points to upper downstream (D1) and foreign means lower downstream (D2) country in the downstream-downstream (D-D) model.

Overall, three patterns of findings deserve more ink. Of less interesting one, as it has been expected, is that non-coordinated policies seems not to cost any non-trivial welfare loss across the linkages and weights in loss function for both home and foreign nations. For instance, the welfare cost of policy non-coordination for member countries occupying different value chains and having equal say in the coordination only amounts to 0.524% for home country and 0.450% for foreign country of steady-state consumption. There is even welfare gain of being self-orientation in the conduct of monetary policy when both member countries compete at the identical value chain of production.

Which brings us to the more interesting finding, that is, welfare performance of policy coordination varies across the nature of bilateral production linkages. Self-oriented policy is welfare superior to coordinated policy when member countries concurrently produce final goods. In contrast, coordinated policy regime becomes welfare superior once member countries specialise in different value chains of production. This is certainly compatible with the findings of existing literature as aforementioned that typically models horizontal intra-industry trade in differentiated final goods while letting the vertical and sequential intra-industry trade in intermediate goods falls through the cracks.

What is most novel is the sizeable welfare cost of non-coordination obtained once we formalise bilateral production linkages that comprise member economies specialising in different value chains of production, and that weigh more heavily the (downstream) country that is nearer to the final consumers in joint monetary policy deliberations. The welfare cost is approximately 3.2% of steady-state consumption in both home and foreign or 6.4% in total. Macroeconomic volatilities, especially for foreign country, decline dramatically when the conduct of policies is coordinated.

The importance of assigning dominant weight to countries positioning itself closer to the final goods market in joint welfare loss consideration is also apparent in the case of D-D model. The trivial welfare gain of Nash policy regime, i.e. 0.068% for home and 0.266% for foreign, falls apart when lower downstream country that is nearer to final goods consumer has larger say in the joint conduct of monetary policy. Non-coordinated policy can be as not-so-trivial as 1.05% of steady-state consumption.

[INSERT TABLE 4]

Role of production linkages: Why is monetary policy coordination suboptimal under downstream-downstream production linkages? Consider a favourable foreign TFP innovation that stimulates the value added of the home and foreign economies as well as reduces the real marginal cost of foreign upstream output. With the resulting decrease in the price of upstream output, the real marginal cost, and correspondingly the price of foreign midstream output will decline as well, as do the real marginal cost and the price of foreign downstream output.

Now, if both countries specialise in downstream production, and note that such a cost-saving TFP innovation is asymmetric because it does not take place in home upstream production, the home economy that imports cheaper intermediates has to cope with terms-of-trade improvement whereas the foreign economy that uses imported intermediates at a price relatively higher than domestic price must address terms-of-trade deterioration. As a consequence, while it is optimal for the foreign central bank to tighten up to stabilise terms-of-trade deterioration, the home benevolent central bank requires monetary expansion in the face of terms-of-trade improvement. Policy coordination implies that either the home or foreign country exacerbates the implications of term-of-trade fluctuation.

Contradictory impact of shock on terms of trade disappears once member countries specialise in different value chains and trade sequentially. For a home economy that specialises in downstream production, a declining price of imported intermediates implies terms-of-trade improvement, which subsidises producer prices for downstream production and results in cheaper final outputs for re-exporting to foreign country. Hence, terms-of-trade improvement at downstream level should have counterbalanced the terms-of-trade deterioration at midstream level in foreign country, thereby improving foreign terms of trade in aggregate. As a result, monetary policy coordination through collective monetary expansion raises the household welfare of both the home and foreign economy by stabilising terms-of-trade fluctuation. And it is unsurprising to see that, as compared with foreign country, the home country (downstream country in our case) that has no offsetting terms-of-trade deterioration in midstream production gains more from policy coordination.

In conclusion, by shedding light on a model with cross-border fragmented chains of production, sequential complementarity in production stages, as in the case of U-D model, makes policies strategically coordinated. In contrast, when countries are competing in identical chain of production, policy coordination turns out to be suboptimal.

6. IS MONETARY POLICY COORDINATION ALWAYS (SUB)OPTIMAL?

We have so far established that the monetary policy coordination is optimal when countries complement each other sequentially throughout the production chains and is suboptimal when countries compete against each other along the same production chains. Thus, it is natural to ask the following: is monetary policy coordination always optimal for countries with a vertically sequential production linkage and suboptimal for the rest? In this section, we provide an answer to this question by examining the sensitivity of the welfare cost of noncoordination to changes in intertemporal and intratemporal elasticity of substitution.

The role of intertemporal and intratemporal elasticity of substitution: There are three key parameters associated with the elasticity of substitution: intertemporal elasticity of substitution, intratemporal elasticity of substitution between home and foreign intermediate inputs, and intratemporal elasticity of substitution between home and foreign final goods. The last of these parameters was preset to a value of 3. Figure 1 illustrates the welfare cost of non-coordination under a upstream-downstream production linkage over empirically reasonable values of intertemporal elasticity of substitution and intratemporal elasticity of substitution between home and foreign intermediate inputs. In particular, given the intratemporal elasticity, the welfare cost of non-coordination falls and becomes negative, implying welfare gain from non-coordination, when the intertemporal elasticity is less than 1 ($\sigma > 1$).

The reasoning is simple. Consider again the favourable foreign TFP shock. As explained earlier in Section 4, positive TFP shock stimulates consumption, and the resulting lower marginal utility requires a rise in wage compensation. The condition $\sigma > 1$ implies that wages rise more than proportionally, taking a toll on private investment. As a result, foreign value added decreases. Meanwhile, home value added increases due to a greater demand for home exports. The home and foreign economy are thus in need of different policy stances: while the home central bank should adopt monetary contraction, monetary expansion is optimal for the foreign central bank. This should offset the welfare gain from policy coordination with respect to terms-of-trade improvement.

It is particularly notable that for larger-than-unitary intertemporal elasticity of substitution ($\sigma < 1$), the welfare cost of non-coordination is approximately zero when the elasticity of substitution between home and foreign intermediate goods is equivalent to that of final goods ($\vartheta = \varphi$). However, when $\vartheta \neq \varphi$, in either way, the welfare cost of non-coordination soars. Interestingly, we can also find this property under D-D model, as illustrated in Figure 2. Although households generally gain from Nash monetary policy action, for $\sigma < 1$ and sufficiently high ϑ, the welfare cost of non-coordination can be non-trivial. This is due to the competing objective of optimal consumption allocation and optimal input allocation in the presence of production fragmentation and dollar-invoiced trade when $\vartheta \neq \varphi$, which may result in inefficient exchange rate fluctuation. The latter produces an unwarranted price disparity between the home and foreign economy for identical goods, a phenomenon dubbed currency misalignment.

[INSERT FIGURES 1 and 2 HERE]

7. THE RECIPE FOR CURRENCY MISALIGNMENT

So far, we have identified that, regardless of the type of production linkage, the welfare cost of non-coordination is minimal when $\vartheta = \varphi$ (i.e., elasticity of substitution between home and foreign intermediate inputs is equivalent to that between home and foreign final goods). In other words, the divergence between ϑ and φ raises the welfare cost of non-coordination. The intuition lies in the share of imported intermediate inputs and the degree of home bias in consumption.

With the capital share of imported intermediate inputs in production, the central bank faces disinflationary bias in that nominal appreciation reduces the price of imported intermediate inputs and thus the overall real marginal cost of production. At the same time, the central bank has expansionary bias, as nominal depreciation can enhance the local-currency denominated profit of export, enabling exporters to reduce the dollar-invoiced export price for foreign market expansion without jeopardising the profit margin.

Therefore, when $\vartheta = \varphi$, the desire to depreciate is exactly offset by the desire to appreciate. Monetary policy is optimal without the need for coordination. Once$\vartheta > \varphi$, disinflationary bias dominates expansionary bias, resulting in nominal appreciation misaligned with optimal consumption allocation. Conversely, expansionary bias dominates disinflationary bias if $\vartheta < \varphi$. The resulting nominal depreciation is then incompatible with the optimal input composition that tilts toward imported intermediate inputs in the production network.

Either way, currency misalignment will arise. When there are currency misalignments, households in the home and foreign economy pay different prices for the same goods, and it is not efficient for the goods to sell at different prices when the real marginal cost remains the same.

Here is the rationale. Combined with the optimal demand schedules, the market clearing condition for home downstream output can be rewritten as

$$Y_{3t} = \gamma \left(\frac{P_{H,t}}{P_t}\right)^{-\varphi} C_t + I_t + (1-\gamma^*) \left(\frac{S_t^* P_{H,t}^D}{P_t^*}\right)^{-\varphi} C_t^* \quad \textbf{(31)}$$

Similarly, for the foreign economy, the market clearing condition is given by

$$Y_{3t}^* = \gamma^* \left(\frac{P_{F,t}^*}{P_t^*}\right)^{-\varphi} C_t^* + i_t^* + (1-\gamma) \left(\frac{S_t P_{F,t}^D}{P_t}\right)^{-\varphi} C_t \quad \textbf{(32)}$$

Given the total downstream output produced and transacted, optimal allocation between home and foreign consumption in both economies, respectively, takes the form

$$\frac{dC_t}{dC_t^*} = -\left(\frac{1-\gamma^*}{\gamma}\right) \left(\frac{P_{H,t}}{S_t^* P_{H,t}^D}\right)^{\varphi} \left(\frac{P_t^*}{P_t}\right)^{\varphi} \quad \textbf{(33)}$$

$$\frac{dC_t}{dC_t^*} = -\left(\frac{\gamma^*}{1-\gamma}\right) \left(\frac{S_t P_{F,t}^D}{P_{F,t}^*}\right)^{\varphi} \left(\frac{P_t^*}{P_t}\right)^{\varphi} \quad \textbf{(34)}$$

Equating the two equations, the world optimal allocation between home and foreign consumption is given by

$$\left(\frac{1-\gamma^*}{\gamma^*}\right) \left(\frac{P_{H,t}}{S_t^* P_{H,t}^D}\right)^{\varphi} = \left(\frac{\gamma}{1-\gamma}\right) \left(\frac{S_t P_{F,t}^D}{P_{F,t}^*}\right)^{\varphi} \quad \textbf{(35)}$$

The crux of the matter is that when trade is invoiced in the U.S dollar, nominal appreciation instead reduces the export profit denominated in local currency. To maintain the profit margin, home exporters increase the dollar price of export $\left(P_{H,t}^D\right)$.

The consequence is that the inefficient price dispersion between goods sold in home market and abroad as $P_{H,t} < S_t^* P_{H,t}^D$ results in an inequality in (35). In contrast, nominal depreciation increases export profit denominated in local currency. Given the profit margin, home exporters could reduce the dollar price of export for foreign market expansion. The outcome is currency misalignment such that $P_{H,t} > S_t^* P_{H,t}^D$. The resulting inequality in (35) indicates suboptimal allocation between home and foreign consumption.

In a world with dollar pricing, even with the assumption of complete exchange rate pass-through, the law of one price can still be violated, which would lead to a reduction in world welfare. The underlying factor is, of course, the asymmetric adjustment in the exchange rate. A nominal depreciation in home currency against the U.S dollar does not imply a nominal appreciation in foreign currency against the U.S dollar, although it still implies a nominal appreciation in foreign currency vis-à-vis home currency.

This is in contrast with the producer-currency (PCP) and local-currency pricing (LCP) mechanisms. Under either mechanism, the adjustment in exchange rates is symmetric: home depreciation implies foreign appreciation, and vice versa. For clarity, let us repeat the procedures outlined above to obtain the world optimal allocation under the respective pricing mechanisms:

$$\text{PCP: } \left(\frac{1-\gamma^*}{\gamma^*}\right)\left(\frac{P_{H,t}}{S_{FH,t}^* P_{H,t}}\right)^{\varphi} = \left(\frac{\gamma}{1-\gamma}\right)\left(\frac{S_{HF,t} P_{F,t}^*}{P_{F,t}^*}\right)^{\varphi} \quad \textbf{(36)}$$

$$\text{LCP: } \left(\frac{1-\gamma^*}{\gamma^*}\right)\left(\frac{P_{H,t}}{S_{FHt}^* P_{H,t}^*}\right)^{\varphi} = \left(\frac{\gamma}{1-\gamma}\right)\left(\frac{S_{HF,t} P_{F,t}}{P_{F,t}^*}\right)^{\varphi} \quad \textbf{(37)}$$

where$S^*_{FH,t}$ denotes the value of foreign currency per unit of home currency, and $S_{HF,t}$ refers to the value of home currency per unit of foreign currency. As $S^*_{FH,t} = \frac{1}{S_{HF,t}}$, Eqs. (36) and (37) can be simplified to

$$\text{PCP: } \left(\frac{1-\gamma^*}{\gamma^*}\right) = \left(\frac{\gamma}{1-\gamma}\right) \quad \textbf{(38)}$$

$$\text{LCP: } \left(\frac{1-\gamma^*}{\gamma^*}\right)\left(\frac{P_{H,t}}{P^*_{H,t}}\right)^{\varphi} = \left(\frac{\gamma}{1-\gamma}\right)\left(\frac{P_{F,t}}{P^*_{F,t}}\right)^{\varphi} \quad \textbf{(39)}$$

It is obvious that for PCP, currency misalignment is impossible as world optimal allocation is not affected by exchange rate fluctuations. Even in the case of LCP, the exchange rate fluctuation plays no role. Demand imbalances across countries are mainly due to pricing-to-market practice.

In conclusion, exchange rate fluctuations under dollar pricing can be inefficient whenever $\vartheta \neq \varphi$ in that it leads to the suboptimal allocation of identical goods across borders. This strongly revives the case for monetary policy coordination. The effect of inefficient exchange rate fluctuation on the price dispersion of identical goods across borders is greater when the degree of home bias in consumption becomes greater.

8. CONCLUSION

This paper revisits a classic issue in international monetary economics: should central banks coordinate the design and conduct of monetary policy? Drawing on the welfare criterion derived from the international business cycle model developed and estimated in Wong and Eng (2012), we show that welfare gain from international monetary policy coordination is conditional upon the variety of production linkages between member economies. If the productions of member countries are linked vertically and sequentially, the welfare cost of uncoordinated policies would be substantial. Self-oriented monetary policy, however, is optimal for open economies that specialise along identical chains of production and thus compete against each other in the intermediate or final goods market. Policy coordination is particularly costly when the economies are concurrently involved in downstream production producing for final consumption.

In the spirit of the existing literature that put great weight on the role of intratemporal and intertemporal elasticity of substitution between home and imported final goods, we shed further light on the interaction between intratemporal elasticity of substitution between home and imported intermediate goods. New and interesting results have been found.

In particular, optimal monetary policy coordination can be viewed as competing objectives of optimal input allocation due to production fragmentation and optimal consumption allocation with home bias when the intratemporal elasticity of substitution between home and foreign final goods is not equivalent to that between home and foreign intermediate goods. The central bank, on the one hand, faces disinflationary bias when nominal appreciation reduces the local price of dollar-invoiced imported intermediate inputs and thus the overall real marginal cost of production. On the other hand, however, the central bank has expansionary bias in assisting exporters penetrating the foreign market by depreciating currency vis-à-vis the U.S dollar. Nominal depreciation feeds into larger local-currency denominated export profit, supporting the reduction in the dollar-invoiced export price without jeopardising the profit margin.

Thanks to the unequal elasticity of substitution between home and foreign intermediate inputs and that for final goods, which should be the norm than the exception, disinflationary and expansionary biases cannot offset each other, contributing to inefficient exchange rate fluctuations. Households in the home and foreign economy pay different prices for the same goods, implying that the law of one price has been violated. Such potential currency misalignment convincingly calls for international monetary policy coordination.

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Table 1
Calibrated parameters, shocks and steady states,2001Q1-2008Q4

	UD Model		DD Model	
	Upstream (U)	Downstream (D)	Downstream (D1)	Downstream (D2)
Parameters				
σ	0.637	0.637	1.020	1.020
γ	0.791	0.480	0.862	0.618
b	0.625	0.625	0.627	0.627
ϑ	1.490	1.490	1.559	1.559
$\mathfrak{F}$	0.905	0.905	0.920	0.920
κ_2	0.548	0.411	0.518	0.610
κ_3	0.693	0.965	0.949	0.752
$\theta_{2\mathscr{h}}$	0.802	0.842	0.657	0.563
$\theta_{3\mathscr{h}}$	0.923	0.922	0.941	0.855
$\theta_{2\mathscr{h}\mathscr{f}}$	0.783	0.708	0.744	0.643
$\theta_{3\mathscr{h}\mathscr{f}}$	0.781	0.733	0.707	0.522
ρ_a	0.719	0.823	0.887	0.884
ρ_I	0.699	0.631	0.612	0.616
Shocks				
u_t^a	0.026	0.029	0.022	0.046
u_t^I	0.023	0.007	0.008	0.026
u_t^C	0.023	0.025	0.030	0.064
$\mathrm{u}_{2\mathscr{h},t}^p$	0.366	0.647	0.065	0.098
$\mathrm{u}_{3\mathscr{h},t}^p$	0.734	0.360	0.855	0.956
$\mathrm{u}_{2\mathscr{h}\mathscr{f},t}^p$	0.384	0.358	0.224	0.573
$\mathrm{u}_{3\mathscr{h}\mathscr{f},t}^p$	0.276	0.537	0.326	0.056
u_t^s	0.008	0.017	0.045	0.036
Steady states				
$\bar{y}_{1ij}/\overline{ex}^i\left(\bar{m}_{1ji}/\overline{\imath m}^i\right)$	0.283	0.283	0.283	0.411
$\bar{y}_{2ij}/\overline{ex}^i\left(\bar{m}_{2ji}/\overline{\imath m}^i\right)$	0.283	0.283	0.283	0.411
$\bar{y}_{3ij}/\overline{ex}^i\left(\bar{c}_{ji}/\overline{\imath m}^i\right)$	0.434	0.434	0.434	0.178
$\bar{c}_i^i/\bar{y}_3^i$	0.616	0.136	0.383	0.408
$\bar{y}_{3ij}/\bar{y}_3^i$	0.023	0.672	0.077	0.373
$\bar{\imath}_i^i/\bar{y}_3^i$	0.362	0.192	0.54	0.219
$\bar{y}_{2ij}/\bar{y}_2^i$	0282	0.718	0.306	0.694
$\bar{y}_{2i}/\bar{y}_2^i$	0.718	0.282	0.694	0.306
$\overline{\imath m}^i/\bar{c}^i$	0.124	0.614	0.614	0.717
$\overline{ex}^i/\bar{c}^i$	0.138	0.736	0.736	0.736

Notes: Parameters and shocks are calibrated on the Bayesian estimated two-country models on East Asia and China, and China and Southeast Asia in Wong and Eng (2012b). UD model is calibrated on the former estimates whereas DD model is calibrated on the latter estimates. Specifically, within their respective bilateral production linkage, Wong and Eng (2012a) have found that the advanced East Asia countries (U) occupy the upstream value chain whereas China (D) at the downstream value chain, while both China (D1) and the developing Southeast Asian (D2) nations compete at downstream value chain (with China occupying higher position).

Table 2
Parameters in welfare criterion

$$\Gamma_{\mathrm{c}} = \frac{\overline{im}}{\bar{c}}\left\{\frac{\bar{c}_{fh}}{\overline{im}} + \frac{\bar{m}_{2fh}}{\overline{im}}.\frac{\bar{c}_{h}}{\bar{y}_3} + \frac{\bar{m}_{1fh}}{\overline{im}}\left(\frac{\bar{y}_{2h}}{\bar{y}_2}.\frac{\bar{c}_{h}}{\bar{y}_3} + \frac{\bar{y}_{2hf}}{\bar{y}_2}.\frac{\bar{y}_{3fh}}{\bar{y}_3^*}\right)\right\}$$
$$- \frac{\overline{ex}}{\bar{c}}\left\{\frac{\bar{y}_{1hf}}{\overline{ex}}.\frac{\bar{y}_{2fh}}{\bar{y}_2^*}.\frac{\bar{c}_{h}}{\bar{y}_3} + \frac{\bar{y}_{3fh}}{\bar{y}_3^*}\left(\frac{\bar{y}_{1hf}}{\overline{ex}}.\frac{\bar{y}_{2f}}{\bar{y}_2^*} + \frac{\bar{y}_{2hf}}{\overline{ex}}\right)\right\}$$

$$\Gamma_{\mathrm{i}} = \frac{\overline{im}}{\bar{c}}.\frac{\bar{c}_{fh}}{\overline{im}} - \Gamma_{\mathrm{c}}$$

$$\Gamma_{\tau} = \frac{\overline{im}}{\bar{c}}.\frac{\bar{c}_{fh}}{\overline{im}} - \Gamma_{\mathrm{c}}$$

$$\Gamma_{tot} = \frac{\overline{im}}{\bar{c}}\left\{\frac{\bar{m}_{2fh}}{\overline{im}}.\frac{\bar{c}_{h}}{\bar{y}_3}.\varphi(1-\gamma) + \frac{\bar{m}_{1fh}}{\overline{im}}.\varphi\left(\frac{\bar{y}_{2h}}{\bar{y}_2}.\left(\frac{\bar{c}_{h}}{\bar{y}_3}(1-\gamma) + \frac{\vartheta\kappa_3}{\varphi}\right) - \gamma.\frac{\bar{y}_{2hf}}{\bar{y}_2}.\frac{\bar{y}_{3fh}}{\bar{y}_3^*}\right)\right.$$
$$\left. - \vartheta\left(\frac{\bar{m}_{1fh}}{\overline{im}}(1-\kappa_2) + \frac{\bar{m}_{2fh}}{\overline{im}}(1-\kappa_3)\right) - \frac{\bar{c}_{fh}}{\overline{im}}.\varphi\gamma\right\}$$

$$- \frac{\overline{ex}}{\bar{c}}\left\{\frac{\bar{y}_{1hf}}{\overline{ex}}.\frac{\bar{y}_{2fh}}{\bar{y}_2^*}\left(\frac{\bar{c}_{h}}{\bar{y}_3}\varphi(1-\gamma) - \vartheta(1-\kappa_3)\right) - \frac{\bar{y}_{3fh}}{\bar{y}_3^*}.\varphi\gamma\left(\frac{\bar{y}_{1hf}}{\overline{ex}}.\frac{\bar{y}_{2f}}{\bar{y}_2^*} + \frac{\bar{y}_{2hf}}{\overline{ex}}\right)\right\}$$

$$\Gamma_{tot^*} = \frac{\overline{im}}{\bar{c}}\left\{\frac{\bar{m}_{1fh}}{\overline{im}}.\varphi\left(\frac{\bar{y}_{2hf}}{\bar{y}_2}.\left(\frac{\bar{c}_{f}^*}{\bar{y}_3^*}(1-\gamma^*) + \frac{\vartheta(1-\kappa_3^*)}{\varphi}\right) - \gamma^*.\frac{\bar{y}_{2h}}{\bar{y}_2}.\frac{\bar{y}_{3hf}}{\bar{y}_3}\right) - \frac{\bar{m}_{2fh}}{\overline{im}}.\frac{\bar{y}_{3hf}}{\bar{y}_3}.\varphi\gamma^*\right\}$$
$$- \frac{\overline{ex}}{\bar{c}}\left\{\vartheta\left(\left(\frac{\bar{y}_{1hf}}{\overline{ex}}.\frac{\bar{y}_{2f}^*}{\bar{y}_2^*} + \frac{\bar{y}_{2hf}}{\overline{ex}}\right)\kappa_3^* + \kappa_2^* - \frac{\bar{y}_{2hf}}{\overline{ex}}\right) - \varphi\gamma^*\left(\frac{\bar{y}_{3hf}}{\overline{ex}} + \frac{\bar{y}_{1hf}}{\overline{ex}}.\frac{\bar{y}_{2f}}{\bar{y}_2^*}.\frac{\bar{y}_{3hf}}{\bar{y}_3}\right)\right.$$
$$\left. + \varphi(1-\gamma^*)\left(\frac{\bar{y}_{1hf}}{\overline{ex}}.\frac{\bar{y}_{2f}^*}{\bar{y}_2^*} + \frac{\bar{y}_{2hf}}{\overline{ex}}\right)\right\}$$

$$\Gamma_{\mathrm{c}}^* = \frac{\overline{im}}{\bar{c}}\left\{\frac{\bar{m}_{2fh}}{\overline{im}}.\frac{\bar{y}_{3hf}}{\bar{y}_3} + \frac{\bar{m}_{1fh}}{\overline{im}}\left(\frac{\bar{y}_{2h}}{\bar{y}_2}.\frac{\bar{y}_{3hf}}{\bar{y}_3} + \frac{\bar{y}_{2hf}}{\bar{y}_2}.\frac{\bar{c}_{f}^*}{\bar{y}_3^*}\right)\right\}$$

$$- \frac{\overline{ex}}{\bar{c}}\left\{\frac{\bar{y}_{3hf}}{\overline{ex}} + \frac{\bar{y}_{1hf}}{\overline{ex}}.\frac{\bar{y}_{2fh}}{\bar{y}_2^*}.\frac{\bar{y}_{3hf}}{\bar{y}_3} + \frac{\bar{c}_{f}^*}{\bar{y}_3^*}\left(\frac{\bar{y}_{1hf}}{\overline{ex}}.\frac{\bar{y}_{2f}^*}{\bar{y}_2^*} + \frac{\bar{y}_{2hf}}{\overline{ex}}\right)\right\}$$

$$\Gamma_{\tau^*} = \frac{\overline{ex}}{\bar{c}}\left(1 - \frac{\bar{y}_{3hf}}{\overline{ex}}\right) - \Gamma_{\mathrm{c}}^*$$

$$\Gamma_{\mathrm{i}^*} = \frac{\overline{im}}{\bar{c}}.\frac{\bar{m}_{1fh}}{\overline{im}}.\frac{\bar{y}_{2hf}}{\bar{y}_2}.\frac{\bar{\iota}^*}{\bar{y}_3^*} - \frac{\overline{ex}}{\bar{c}}.\frac{\bar{\iota}^*}{\bar{y}_3^*}\left(\frac{\bar{y}_{1hf}}{\overline{ex}}.\frac{\bar{y}_{2f}^*}{\bar{y}_2^*} + \frac{\bar{y}_{2hf}}{\overline{ex}}\right)$$

Table 3

Parameterising the welfare loss function

	Upstream-downstream model				Downstream-downstream model			
	Nash regime		Coordinated regime		Nash regime		Coordinated regime	
	Downstream	Upstream	Downstream	Upstream	Downstream (D1)	Downstream (D2)	Downstream (D1)	Downstream (D2)
π_{3h}	1904.22	1311.57	952.11	655.78	3477.25	317.40	1738.63	158.70
π_{fh}	0.61	0.12	0.31	0.06	0.61	0.72	0.31	0.36
π_{hf}	-0.74	-0.14	-0.37	-0.07	-0.74	-0.74	-0.37	-0.37
$\mathbb{Y}$	0.81	0.37	0.40	0.18	-0.04	-0.02	-0.02	-0.01
$\mathcal{G}^{i}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$\mathcal{G}^{c}$	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00
τ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
τ^{*}	0.09	0.00	0.04	0.00	-0.01	0.00	0.00	0.00
tot	0.18	0.00	0.09	0.00	-0.01	0.00	-0.01	0.00
$\mathcal{G}^{tot}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$y^{\mathcal{G}}$	-1.35	-35.13	-0.67	-17.56	-0.50	-3.02	-0.25	-1.51
π_{w}	-1123.08	-29239.95	-561.54	-14619.97	-413.21	-2503.50	-206.61	-1251.75

Notes: Downstream country (D1) is positioned at higher value-added chain of production compared with downstream country (D2) in downstream-downstream model.

Table 4
Macroeconomic volatility and welfare loss

	Nash Policy Regime		Coordinated Policy Regime					
	D-D	U-D	Downstream-downstream (D-D)			Upstream-downstream (U-D)		
Standard deviation			Equal weight $\rho = 0.5$	Upper downstream dominant $\rho = 0.8$	Lower downstream dominant $\rho = 0.2$	Equal weight $\rho = 0.5$	Upstream dominant $\rho = 0.2$	Downstream dominant $\rho = 0.8$
GDP	0.174	0.077	0.176	0.165	0.181	0.068	0.054	0.067
	(0.171)	(0.055)	(0.171)	(0.133)	(0.154)	(0.042)	(0.054)	(0.041)
Cons.	0.082	0.096	0.031	0.058	0.028	0.049	0.081	0.082
	(0.258)	(0.077)	(0.258)	(0.164)	(0.219)	(0.054)	(0.051)	(0.036)
Inv.	0.019	0.012	0.014	0.022	0.015	0.024	0.017	0.015
	(0.055)	(0.059)	(0.050)	(0.042)	(0.051)	(0.077)	(0.062)	(0.077)
Export	0.574	0.565	0.474	0.510	0.419	0.232	0.391	0.328
	(0.166)	(0.550)	(0.153)	(0.163)	(0.179)	(0.232)	(0.405)	(0.380)
Import	0.267	0.430	0.223	0.307	0.305	0.155	0.334	0.204
	(0.227)	(0.256)	(0.178)	(0.222)	(0.151)	(0.068)	(0.156)	(0.117)
Exp. price inflation	2.667	5.126	2.071	2.056	2.108	2.425	3.704	1.722
	(2.067)	(3.443)	(1.579)	(1.540)	(1.650)	(1.566)	(3.008)	(1.794)
Im. Price inflation	2.334	4.914	1.283	1.344	1.379	2.216	4.448	2.283
	(1.499)	(3.668)	(1.376)	(1.426)	(1.404)	(1.907)	(2.672)	(1.708)
Domestic inflation	0.025	0.044	0.010	0.016	0.026	0.014	0.064	0.018
	(0.046)	(0.009)	(0.056)	(0.043)	(0.052)	(0.007)	(0.006)	(0.005)
CPI inflation	0.023	0.064	0.024	0.020	0.048	0.065	0.073	0.062
	(0.298)	(0.071)	(0.257)	(0.232)	(0.208)	(0.023)	(0.043)	(0.035)
Terms of trade	0.137	0.175	0.093	0.153	0.152	0.14	0.198	0.080
	(0.137)	(0.175)	(0.093)	(0.153)	(0.152)	(0.14)	(0.198)	(0.080)
Exchange rate	0.081	0.353	0.124	0.114	0.226	0.135	0.218	0.117
	(0.732)	(0.724)	(0.641)	(0.539)	(0.562)	(0.112)	(0.313)	(0.142)
	Welfare loss		Unconditional welfare cost of noncoordination (%)					
$\mathbb{W}$	-4.127	4.915	0.068	0.083	-1.048	-0.524	-0.831	-3.248
$\mathbb{W}^*$	-17.323	0.000	0.266	0.281	-0.850	-0.450	-0.757	-3.174

Notes: * denotes foreign country. In D-D model, upper (lower) downstream country is taken as home (foreign). Whereas in U-D model, upstream country is foreign while downstream country is home. See notes in Table 1 for the source of country classification.

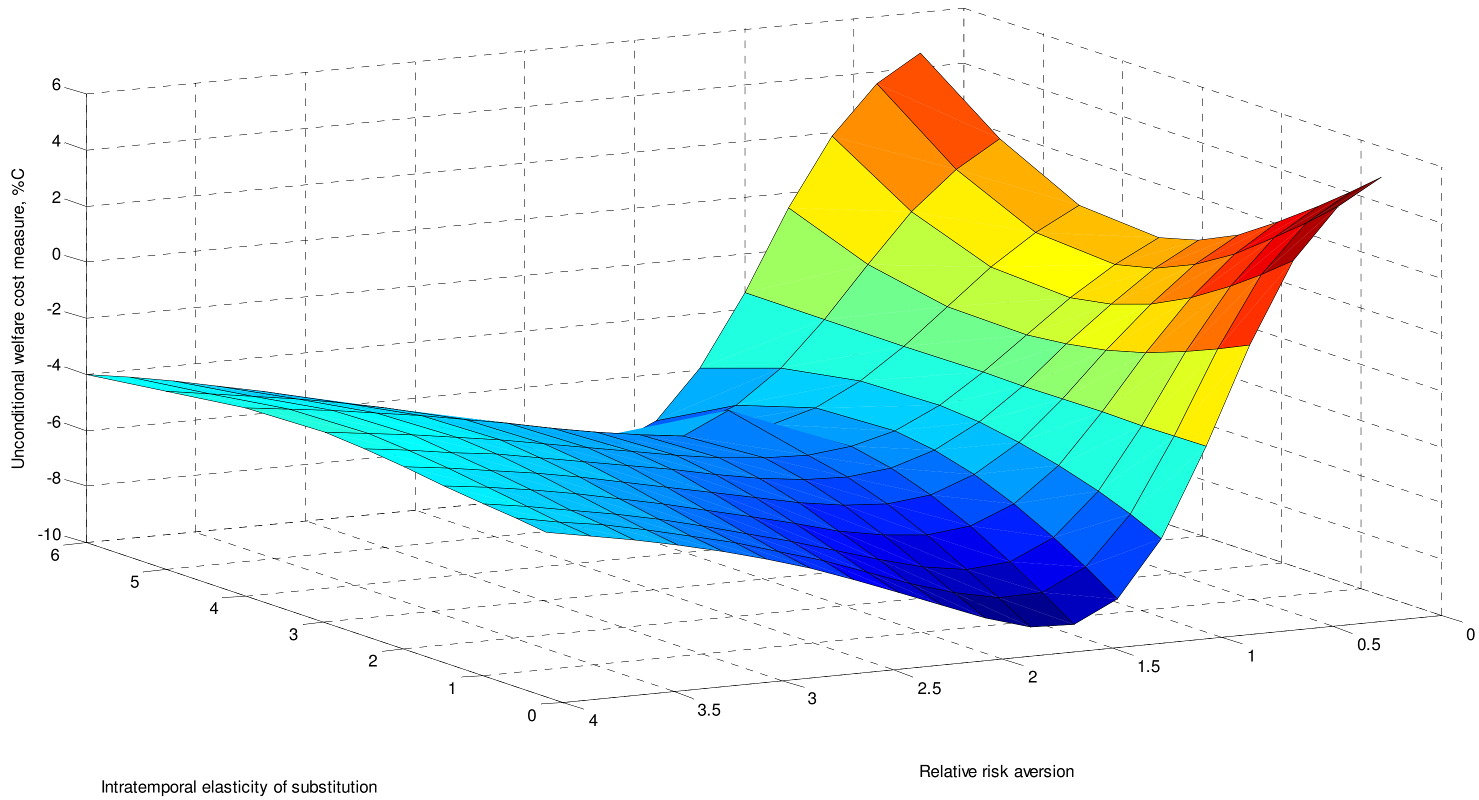

FIGURE 1. Welfare cost of noncoordination under upstream-downstream production linkage

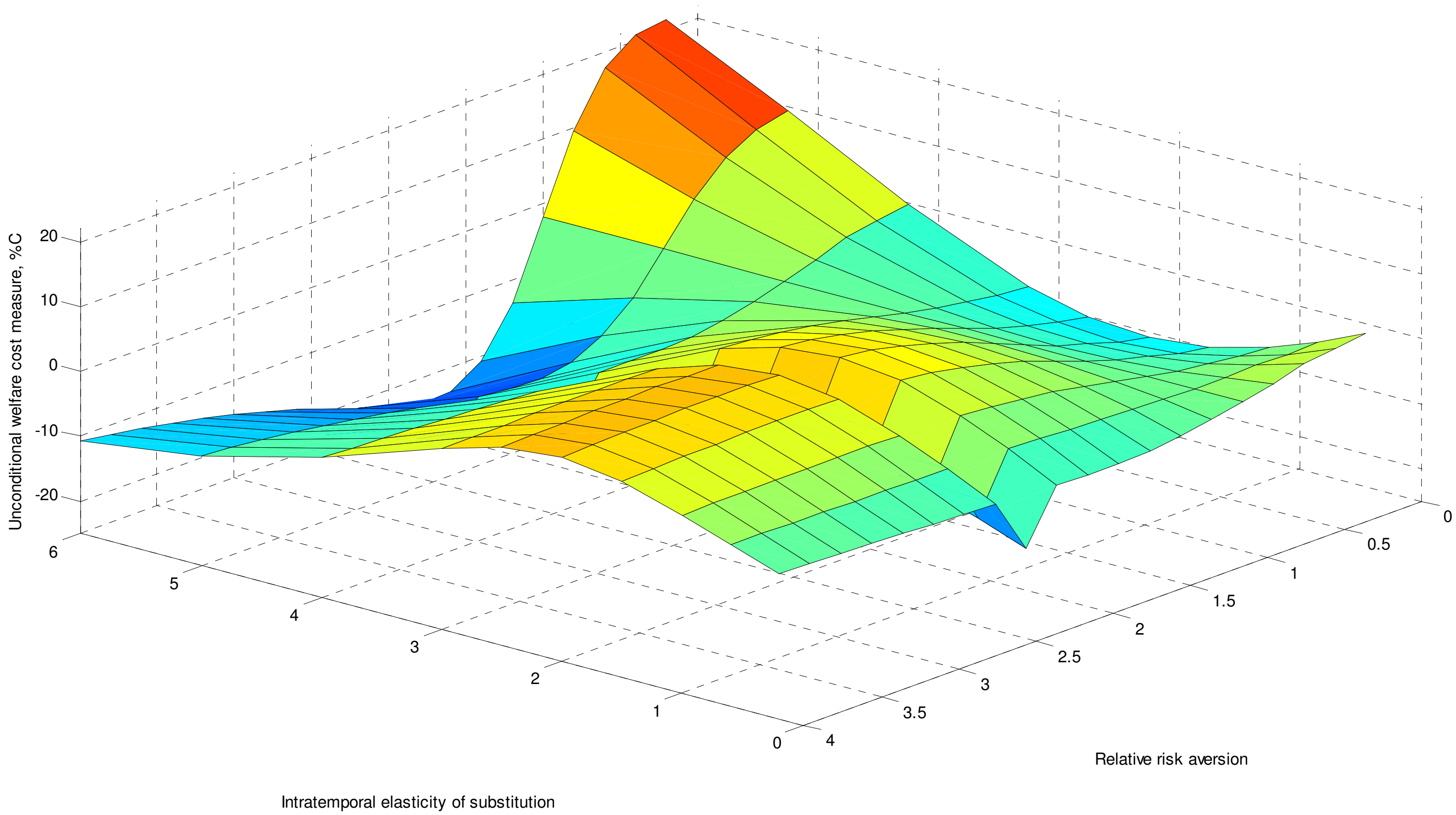

FIGURE 2. Welfare cost of noncoordination under downstream-downstream production linkage