When measurement of trade in value added meets inspection of shock propagation in New Keynesian model

Chin-Yoong Wong[a,*] Yoke-Kee Eng[a]

[a]*Department of Economics, Faculty of Business and Finance, Universiti Tunku Abdul Rahman, Jalan Universiti, Bandar Barat 31900 Kampar, Perak, Malaysia.*

[*] *Corresponding author. Tel: 6054688888, ext. 1035. Fax: 6054667407. Email address: wongcy@utar.edu.my*

Abstract

This paper aims to bring the measurement of cross-border flows of value added as a result of production fragmentation together with the inspection of shock propagation in a unified framework. First, we propose a New Keynesian model of vertical specialization, through which to show that any open-economy model attempting to investigate macroeconomic implications of production fragmentation shall pass the litmus test of being able to account for the breakdown of gross exports into domestic and foreign value added according to what the empirical literature has advanced. Second, we use the framework estimated with Bayesian method to inspect shock propagation across countries positioned at different stages in production sharing. We find that responses of countries bound but positioned at different stages in production sharing tend to be synchronized. The magnitude of response toward common and country-specific shocks is also shaped by the country upstreamness.

Keywords: Production sharing; Production fragmentation; Vertical specialization; New Keynesian; Bayesian estimation

JEL classification: F14, F41, F44,

1. Introduction

One of the defining characteristics of today's international trade is the heavy flow of parts and components across countries. Underlying the fast-growing world trade since trade barrier reduction in 1980s, which brings about the integration of majority developing countries into world economy, is the reorganization of production structure. Productions are vertically sliced and fragmented across countries with different factor endowments, and as a result, multiple back-and-forth trades in intermediate goods are generated before a final product is assembled (Feenstra 1998).

That said, it means gross values of exports and imports are no longer an appropriate measure of a country's integration into world economy given the fact that the gross values now comprise foreign value added embodied in the intermediates used, which may, in turn, contain domestic value added embodied in home intermediates exported for foreign intermediates production at earlier stage. Who produces for whom, in Daudin et al. (2011)'s term, becomes a puzzle waiting to be solved. As a response to this measurement challenge, an active literature has been kindled since the influential Hummels et al. (2001) that define the meaning of vertical specialization, upon which many subsequent empirical works have adopted and improved.

But the importance of tracing the sources of value added embodied in trade apparently goes beyond the measurement challenge itself. When countries are bound with global production sharing, how does shock propagate across chains of production? Does it matter in terms of magnitude of responses whether a country lies in the upstream or downstream of production in the face of supply and demand shocks? Understanding macroeconomic interdependence between countries participating in production sharing, as we believe, is fundamentally critical for other more important macroeconomic questions such as the design of optimal monetary coordination.

To take up this challenge, this paper blends the recent actively growing works on measurement of trade in value added using global input-output framework with the workhorse two-country New Keynesian macroeconomic model. We attain this goal by first extending the workhorse Smets and Wouters (2003)'s model to incorporate three sequential processing stages. The questions like whether or not a country participates in production fragmentation, and if yes, by specializing at upstream or midstream or downstream production, are endogenously determined by the data using Bayesian estimation.

Built on the work by Johnson and Noguera (2012a, 2012b), Daudin et al. (2011), Hummels et al. (2001), and particularly Koopman et al. (2010), we decompose the gross exports generated from our Bayesian estimated model into domestic and foreign value added following exactly the most comprehensive definition of value-added trade available in the empirical literature. Through macroeconomic lens, we are able to know in where the value added embodied and to what uses the value added are put. As a further, in the spirits of Johnson and Noguera (2012a, 2012b) we also identify the extent of bilateral production fragmentation, and in line with

Koopman et al. (2010) we have constructed an index that gauges the country upstreamness in production sharing.

In fact, we are not the first to set up a model wherein final output is produced through three sequential production stages. Yi (2003) did. What distinguish ours from Yi (2003)'s dynamic Ricardian trade model with nontradable final goods, however, is that outputs of all stages in our model are tradable. This simple innovation is proved to be fundamental in accounting for domestic value added embodied in export of intermediates shipped back to source for downstream production as well as foreign content in domestic final goods export. We thus argue that any model of international business cycle attempting to investigate macroeconomic implications of vertical specialization shall pass the litmus test of being able to account for the breakdown of gross exports into domestic and foreign value added as the empirical literature has advanced.

Next, we use the framework to shed some lights on shock propagation. We find that irrespective of the origins of favorable total factor productivity shock, whether from upstream or downstream country, aggregate value added of countries bound but positioned at different stages in production sharing tend to be jointly lifted up. In other words, vertical linkage in production has synchronized the responses of participating countries toward shocks (di Giovanni and Levchenko, 2010). The responses of upstream country are magnified when its own shock correlates with the shock originated in downstream country. This conjecture corroborates the recent empirical finding on the role of vertical specialization in great trade collapse (Bems et al. 2010; Levchenko et al., 2010)

2. A New Keynesian model of vertical specialization: Key ingredients

In this section we lay out a two-region New Keynesian model of vertical specialization. There are two innovations to an otherwise standard New Keynesian model. Firstly, final output is processed through three sequential stages. The upstream firms combine labor services and capital in Cobb-Douglas production technology to produce materials partially exported abroad as input for subsequent processing, with the remaining for local midstream remanufacturing in conjunction with imported intermediate inputs. A fraction of the remanufactured intermediate goods would then be re-exported for final assembly in downstream production. The assembled final goods are to be consumed and invested locally as well as exported. Invested final goods constitute the capital inputs for upstream production, which later on becomes the intermediates for subsequent processing. As such, we have laid out a model of production fragmentation with "intermediate loops". Figure 1 provides illustrations on this structure of production and trade.

--- [INSERT FIGURE 1 HERE] ---

While a typical New Keynesian model with two stages of production can account for *import of intermediates for final assembly and export* in sequence, our model embraces at the same time the equally if not more important *sequential import and* *export of intermediate inputs*. With this relatively parsimonious model we can comprehensively trace the cross-border flow of value added in the spirit of Koopman et al. (2010).

The second innovation is the assumption of U.S dollar invoicing in trade, motivated by the fact that international trade is mostly priced in U.S dollar (Goldberg and Tille, 2008). This is in contrast to the typical practice in New Open-Economy Macroeconomics that assumes either producer or local currency pricing.

Given the dollar price of export, depreciation against the U.S dollar raises unit export price in local currency. Although nominal depreciation is passed through completely into higher local price of imported intermediate inputs, the expanding local-currency denominated export revenue helps firms to absorb the negating impact of depreciation on markup without the need to raise output price for home and export market proportionally. As such, dollar pricing mechanism interestingly lies in between zero exchange rate pass-through into output price under local currency pricing on one spectrum and complete exchange rate pass-through into output price under producer currency pricing on another spectrum, while retaining the feature of close movement between nominal exchange rate and terms of trade[1]. (see Devereux and Engel.

We now turn to more elaborated discussion of the model.

---

[1] See Devereux and Engel (2007) for ingenious way to reconcile the facts that exchange rate pass-through into consumer price is weak and that exchange rates are highly correlated with the relative price of imports to exports.

2.1. Chains of production from upstream to midstream and downstream

A unit mass of competitive firms at upstream production has access to Cobb-Douglas production technology of (1) that uses plant-specific capital K_{t-1}^{j}, $j \in J$, and a continuum of differentiated labours $N_t \left(= \left[\int_{i \in I} N_t(i)^{\frac{\varepsilon_{N,t}-1}{\varepsilon_{N,t}}} di \right]^{\frac{\varepsilon_{N,t}}{\varepsilon_{N,t}-1}} \right)$ to produce plant-specific materials Y_{1t}^{j} at date *t*.

$$Y_{1t}^{j} = e^{A_t} \left(K_{t-1}^{j} \right)^{\alpha} (N_t)^{1-\alpha} \tag{1}$$

where A_t is an first-order autoregressive Hicks-neutral total factor productivity (TFP) shock. The upstream firms can only alter its capital over time by varying the rate of investment I_t^j that comes with a cost $\mathrm{S}\left(I_t^j / I_{t-1}^j\right)$. Capital stock accumulation evolves according to the form in Mandelman et al. (2011)

$$K_t^j = (1-\delta) K_{t-1}^{j} + \mathrm{u}_t^I I_t(j) \left\{ 1 - \frac{\Psi}{2} \left(\frac{\mathrm{u}_{t-1}^I I_{t-1}(j)}{\mathrm{u}_t^I I_t(j)} \right) \left(\frac{u_t^I I_t(j)}{u_{t-1}^I I_{t-1}(j)} - \Lambda \right)^2 \right\} \tag{2}$$

where u_t^I is investment-specific technology (IST) shock, and follows first-order autoregressive process. The parameter Ψ denotes investment adjustment cost, and Λ determines how forward-looking the investment decision is.

The upstream firm thus optimally chooses the path of K_t^j, N_t, and I_t^j to minimize the cost of production $r_{K,t} K_t^j + W_t N_t$ subject to output net of investment adjustment cost, $\Phi_{1t}^{j} \left\{ e^{A_t} \left(K_{t-1}^{j} \right)^{\alpha} (N_t)^{1-\alpha} - \frac{\Psi}{2} \mathrm{u}_{t-1}^{I} I_{t-1}^{j} \left(\frac{u_t^I I_t^j}{u_{t-1}^I I_{t-1}^j} - \Lambda \right)^2 = 0 \right\}$, where Φ_{1t}^{j} is Lagrangian multiplier which we define as the real marginal cost for upstream firm.

$W_t \left(= \left[\int_{i \in I} W_t(i)^{\frac{\varepsilon_{N,t}-1}{\varepsilon_{N,t}}} di \right]^{\frac{\varepsilon_{N,t}}{\varepsilon_{N,t}-1}} \right)$ refers to the real wage and $r_{K,t}$ is the real return on capital, which correspond to respective marginal productivity. $\varepsilon_{N,t}$ denotes the wage elasticity of the demand for labor i. For the sake of simplicity, we assume that the market for upstream goods is tightly competitive. The elasticity of substitution between varieties is thus close to infinity, and as a consequence, price approximates real marginal cost. The output are used as intermediates for either domestic or foreign midstream production, $Y_{1t}^{j} \equiv Y_{1ht}^{jh} + Y_{1t}^{jf}$[2]. The marginal product of capital stock and labor, and the intertemporal optimal investment decision are derived as

$$K_{t-1}^{j} = \left(\frac{1}{r_{K,t}}\right) \alpha \Phi_1 Y_{1t}^{j} \tag{3}$$

$$N_t = \left(\frac{1}{W_t}\right) (1-\alpha) \Phi_1 Y_{1t}^{j} \tag{4}$$

$$\Phi_{1t} \left(\frac{u_t^I I_t^j}{u_{t-1}^I I_{t-1}^j} - \Lambda \right) = \Phi_{1t+1} \left\{ \left(\frac{u_{t+1}^I I_{t+1}^j}{u_t^I I_t^j} - \Lambda \right) \left(\frac{u_{t+1}^I I_{t+1}^j}{u_t^I I_t^j} \right) - \frac{1}{2} \left(\frac{u_{t+1}^I I_{t+1}^j}{u_t^I I_t^j} - \Lambda \right)^2 \right\} \tag{5}$$

Eqs. (3) and (4) combined with (1) give us the real marginal cost of upstream firm.

$$\Phi_{1t}^{j} = \frac{\left(r_{K,t}^{j} + \delta\right)^{\alpha} (W_t)^{1-\alpha}}{e^{A_t} \alpha^{\alpha} (1-\alpha)^{1-\alpha}} \tag{6}$$

A mass continuum of midstream monopolistically competitive firm j, $j \in J$, imports c.i.f upstream goods $M_{1f,t}^{jh}$ of plant j for remanufacture in combination with local inputs $Y_{1h,t}^{jh}$ using CES production technology as in (7)

[2] The subscripts h and f indicate origin of production, whereas the superscript h and f denote destination of export. For instance, $Y_{1f,t}^{h}$ indicates foreign output exported to home country whereas $Y_{1h,t}^{f}$ refers to home output exported to foreign country.

$$Y_{2t}^{j} = \left[(1-\kappa_2)^{\frac{1}{\vartheta}}\left(Y_{1h,t}^{jh}\right)^{\frac{\vartheta-1}{\vartheta}} + (\kappa_2)^{\frac{1}{\vartheta}}\left(M_{1f,t}^{jh}\right)^{\frac{\vartheta-1}{\vartheta}}\right]^{\frac{\vartheta}{\vartheta-1}} \tag{7}$$

where $M_{1f,t}^{jh} = \left(\int_{j\in J} M_{1f,t}^{jh}(j)^{\frac{\varepsilon_{2t}-1}{\varepsilon_{2t}}} dj\right)^{\frac{\varepsilon_{2t}}{\varepsilon_{2t}-1}}$ and $Y_{1h,t}^{jh} = \left(\int_{j\in J} Y_{1h,t}^{jh}(j)^{\frac{\varepsilon_{2t}-1}{\varepsilon_{2t}}} dj\right)^{\frac{\varepsilon_{2t}}{\varepsilon_{2t}-1}}$. The optimal demand function for the j varieties of $M_{1f,t}^{jh}(j)$ is $\left(P_{1f,t}^{j}(j)/P_{1f,t}^{j}\right)^{-\varepsilon_{2t}} M_{1f,t}^{jh}$, and of $Y_{1h,t}^{jh}(j)$ is $\left(P_{1h,t}^{j}(j)/P_{1h,t}^{j}\right)^{-\varepsilon_{2t}} Y_{1h,t}^{jh}$. $P_{1h,t}^{j}$ and $P_{1f,t}^{j}$ are the domestic price of local and imported materials, respectively. $\varepsilon_{2t} > 1$ is the time-varying demand elasticity. The parameter κ_2 indicates the share of imported intermediates in midstream production, and the parameter $\vartheta > 0$ denotes the elasticity of substitution between home and imported intermediate inputs.

Midstream firm j minimizes the cost function $P_{1h,t}^{j} Y_{1h,t}^{jh} + P_{1f,t}^{j} M_{1f,t}^{jh}$ subject to $\Phi_{2t}^{j}\left\{Y_{2t}^{j} - \left[(1-\kappa_2)^{\frac{1}{\vartheta}}\left(Y_{1f,t}^{jh}\right)^{\frac{\vartheta-1}{\vartheta}} + \kappa_2^{\frac{1}{\vartheta}}\left(M_{1f,t}^{jh}\right)^{\frac{\vartheta-1}{\vartheta}}\right]^{\frac{\vartheta}{\vartheta-1}}\right\}$, where Φ_{2t}^{j} is real marginal cost of midstream firm to obtain the following optimal demand schedules for domestic and foreign inputs

$$Y_{1h,t}^{j} = (1-\kappa_2)\left(\frac{P_{1h,t}^{j}}{P_{1,t}^{j}}\right)^{-\vartheta} Y_{2t}^{j} \tag{8}$$

$$M_{1f,t}^{jh} = \kappa_2\left(\frac{P_{1f,t}^{j}}{P_{1,t}^{j}}\right)^{-\vartheta} Y_{2t}^{j} \tag{9}$$

By substituting the first-order condition for $Y_{1h,t}^{jh}$ and $M_{1f,t}^{jh}$, we can obtain the real marginal cost for midstream firm.

$$\Phi_{2t}^{j} = P_{1t}^{j} = \left[(1-\kappa_2)\left(P_{1h,t}^{j}\right)^{1-\vartheta} + \kappa_2\left(P_{1f,t}^{j}\right)^{1-\vartheta}\right]^{\frac{1}{1-\vartheta}} \tag{10}$$

Note that P_{1t}^{j} is the flexible production-based producer price for midstream production. The market is cleared by the demand from home and foreign downstream firm, $Y_{2t}^{j} \equiv Y_{2h,t}^{jh} + Y_{2h,t}^{jf}$.

Lastly at downstream production, a continuum of monopolistically competitive final-good producers j of measure J combines a variety of home $Y_{2h,t}^{jh}$ and imported intermediate goods $M_{2f,t}^{jh}$ using the following CES technology to produce consumer goods.

$$Y_{3t}^{j} = \left[(1-\kappa_3)^{\frac{1}{\vartheta}}\left(Y_{2h,t}^{jh}\right)^{\frac{\vartheta-1}{\vartheta}} + \kappa_3^{\frac{1}{\vartheta}}\left(M_{2f,t}^{jh}\right)^{\frac{\vartheta-1}{\vartheta}}\right]^{\frac{\vartheta}{\vartheta-1}} \tag{11}$$

where $Y_{2h,t}^{jh} = \left(\int_{j\in J} Y_{2h,t}^{jh}(j)^{(\varepsilon_{3t}-1)/\varepsilon_{3t}} dj\right)^{\frac{\varepsilon_{3t}}{\varepsilon_{3t}-1}}$ and $M_{2f,t}^{jh} = \left(\int_{j\in J} M_{2f,t}^{jh}(j)^{(\varepsilon_{3t}-1)/\varepsilon_{3t}} dj\right)^{\frac{\varepsilon_{3t}}{\varepsilon_{3t}-1}}$. The demand schedules for j varieties of domestic and imported intermediates take the form $Y_{2h,t}^{jh}(j) = \left(P_{2h,t}^{j}(j)/P_{2h,t}^{j}\right)^{-\varepsilon_{3t}} Y_{2h,t}^{jh}$ and $M_{2f,t}^{jh}(j) = \left(P_{2f,t}^{j}(j)/P_{2f,t}^{j}\right)^{-\varepsilon_{3t}} M_{2f,t}^{jh}$. The parameter κ_3 denotes the share of imported intermediate inputs in final-good production. Subject to $\Phi_{3t}^{j}\left\{Y_{3t}^{j} - \left[(1-\kappa_3)^{\frac{1}{\vartheta}}\left(Y_{2h,t}^{jh}\right)^{\frac{\vartheta-1}{\vartheta}} + \kappa_3^{\frac{1}{\vartheta}}\left(M_{2f,t}^{jh}\right)^{\frac{\vartheta-1}{\vartheta}}\right]^{\frac{\vartheta}{\vartheta-1}}\right\}$, where Φ_{3t}^{j} is real marginal cost of downstream firm, likewise, downstream firm j minimizes the cost function $P_{2h,t}^{j} Y_{2h,t}^{jh} + P_{2f,t}^{j} M_{2f,t}^{jh}$ to yield the following optimal demand for domestic and imported intermediates.

$$Y_{2h,t}^{j} = (1-\kappa_3)\left(\frac{P_{2h,t}^{j}}{P_{2,t}^{j}}\right)^{-\vartheta} Y_{3t}^{j} \tag{12}$$

$$M_{2f,t}^{jh} = \kappa_3 \left(\frac{P_{2f,t}^{j}}{P_{2,t}^{j}}\right)^{-\vartheta} Y_{3t}^{j} \tag{13}$$

The real marginal cost for downstream firm is derived as

$$\Phi_{3t}^{j} = P_{2t}^{j} = \left[(1-\kappa_3)\left(P_{2h,t}^{j}\right)^{1-\vartheta} + \kappa_3\left(P_{2f,t}^{j}\right)^{1-\vartheta}\right]^{\frac{1}{1-\vartheta}} \tag{14}$$

P_{2t}^{j} is staggered producer price index for downstream firms. The final output is partly consumed by domestic and foreign consumers with the remaining invested as capital stock to produce upstream goods, $Y_{3,t}^{j} \equiv C_{h,t}^{ih} + Y_{3h,t}^{jf} + I_t^{j}$.

2.2. Transportation cost

Following Ravn and Mazzenga (2004), we measure transportation cost as the wedge between c.i.f. value of import and the corresponding f.o.b. value of export in such a way that

$$1 + \tau_t = \frac{M_{1f,t}^{jh}}{Y_{1f,t}^{jh}} = \frac{M_{2f,t}^{jh}}{Y_{2f,t}^{jh}} = \frac{C_{f,t}^{ih}}{Y_{3f,t}^{jh}} \tag{15}$$

2.3. Optimal pricing decision with U.S dollar pricing in trade

Pricing decision is assumed to be time dependent. The ability of domestic firms at midstream and downstream production to re-optimize the price is subject to the signal received at probability $1-\theta_{Pn}$, for $n = 2,3$. Firm j that receives the signal chooses $\mathbb{P}_{nh,t}$ to maximize the following expected discounted profits $E_t\Pi_t$ for sales in home market

$$E_t\Pi_t^{home} = E_t \sum_{i=0}^{\infty} (\theta_{Pn}\beta)^i \Lambda_{t+i} \left[\frac{\mathbb{P}_{nh,t+i}^{j} - MC_{n,t+i}}{P_{n,t+i}}\right]\left[\frac{\mathbb{P}_{nh,t+i}^{j}}{P_{nh,t+i}}\right]^{-\varepsilon_{n,t}} Y_{nh,t+i}^{jh} \tag{16}$$

Contrary to producer-currency pricing decision in the typical New Keynesian model, or local-currency pricing in the New Open-Economy model, we consider U.S. dollar pricing strategy in exports. This assumption is apparently coherent with the fact that international trade is largely denominated in the U.S dollar (Goldberg and Tille, 2008). The variability of exchange rates between local currency and the U.S. dollar $S_{hd,t}$ will not pass through into foreign price of home export, but rather, it will pass through into local-currency denominated export earnings. Firm j signaled for price reoptimization chooses $\mathbb{P}^{d}_{nh,t}$to maximize the expected export profit in home currency

$$E_t \Pi_t^{DP} = E_t \sum_{i=0}^{\infty} (\theta^{*}_{Pn}\beta)^i \Lambda_{t+i} \left[\frac{S_{hd,t}\mathbb{P}^{d}_{nh,t+i}(j) - MC_{n,t+i}}{P_{n,t+i}}\right] \left[\frac{S_{fd,t}\mathbb{P}^{d}_{nh,t+i}(j)}{P^{f}_{nh,t+i}}\right]^{-\varepsilon_{n,t}} Y^{jf}_{nh,t+i} \quad (17)$$

In what follows we assume that all firms are symmetric in price setting.

Firms allowed for price re-optimization will reset their log-linearized price $\widehat{\mathbb{P}}^{new}_{nh,t}$ to approximate the optimal reset price derived from (16) and (17), respectively, for home and export market. The remaining firms that do not receive signal for re-optimization will stick to last-period price, out of which a fraction of them γ_{Pn} will index to last-period inflation. Probability-weighted inflation dynamics of producer price ($\pi_{2h,t}$), GDP deflator ($\pi_{3h,t}$), intermediate export price ($\pi^{d}_{2h,t}$) and final export prices ($\pi^{d}_{3h,t}$) can be derived as

$$\pi_{nh,t} = \left(\frac{\gamma_{Pn}}{1+\theta_{Pn}\beta\gamma_{Pn}}\right)\pi_{nh,t-1} + \left(\frac{\beta}{1+\theta_{Pn}\beta\gamma_{Pn}}\right)E_t\pi_{nh,t+1} + \lambda\left(\widehat{\Phi}_{n,t} + \hat{\mu}_{n,t}\right) \quad (18)$$

$$\pi^{d}_{nh,t} = \left(\frac{\gamma^{d}_{pn}}{1+\theta^{d}_{pn}\beta\gamma^{d}_{pn}}\right)\pi^{d}_{nh,t-1} + \left(\frac{\beta}{1+\theta^{d}_{pn}\beta\gamma^{d}_{pn}}\right)E_t\pi^{d}_{nh,t+1} + \lambda^{d}\left(\widehat{\Phi}_{n,t} - \hat{s}_{hd,t} + \hat{\mu}^{d}_{n,t}\right) \quad (19)$$

where $\lambda = \frac{(1-\theta_{Pn})(1-\theta_{Pn}\beta)}{\theta_{Pn}(1+\theta_{Pn}\beta\gamma_{Pn})}$ and $\lambda^d = \frac{(1-\theta_{pn}^d)(1-\theta_{pn}^d\beta)}{\theta_{pn}^d(1+\theta_{pn}^d\beta\gamma_{pn}^d)}$. $\hat{\mu}_{n,t}$ is an i.i.d price markup shock for $n = 2,3$. $\widehat{\Phi}_{n,t}$ is the log-deviation of real marginal cost, in which $\widehat{\Phi}_{2,t} = \hat{p}_{1,t}$ and $\widehat{\Phi}_{3,t} = \hat{p}_{2,t}$.

2.4. Household

Consider a continuum of infinitely-lived households, represented and indexed by $i \in [0,1]$, who possess the utility function of

$$U = E_t\left\{\sum_{t=0}^{\infty}\beta^t \mathrm{u}_t^C\left[\frac{(C_t^i - H_t)^{1-\sigma}}{1-\sigma} - \mathrm{u}_t^N\frac{(N_t^i)^{1+\chi}}{1+\chi}\right]\right\} \tag{20}$$

where

$$C_t^i = \left[(\gamma)^{\frac{1}{\varphi}}\left(C_{h,t}^{ih}\right)^{\frac{\varphi-1}{\varphi}} + (1-\gamma)^{\frac{1}{\varphi}}\left(C_{f,t}^{ih}\right)^{\frac{\varphi-1}{\varphi}}\right]^{\frac{\varphi}{\varphi-1}} \tag{21}$$

u_t^C and u_t^N, respectively, are i.i.d preference and labor supply shock. $C_{h,t}^{ih}\left\{= \left(\int_{i\in I} C_{h,t}^{ih}(i)^{\frac{\varepsilon_t-1}{\varepsilon_t}}dj\right)^{\frac{\varepsilon_t}{\varepsilon_t-1}}\right\}$ and $C_{f,t}^{ih}\left\{= \left(\int_{i\in I} C_{f,t}^{ih}(i)^{\frac{\varepsilon_t-1}{\varepsilon_t}}dj\right)^{\frac{\varepsilon_t}{\varepsilon_t-1}}\right\}$ are the composite varieties of home and imported consumer goods. $H_t(= bC_{t-1}^i)$ indicates external habit formation in which b is the parameter that governs the extent of habit persistence. $0 < \beta < 1$ refers to subjective discount factor, σ measures the coefficient of relative risk aversion, and the reciprocal of χ indicates the wage elasticity of labor supply. The parameter $\varphi > 1$ denotes the elasticity of substitution between home and imported consumer goods. The parameter γ measures home bias. Household i's constrained optimization problem can be illustrated as utility maximization of (20) subject to (21) and the following flow budget constraint

$$C_t + \left(\frac{S_{hd,t}}{P_t \omega_t}\right)\left(\frac{B_t^f}{R_t^{us}}\right) + \frac{B_t}{P_t R_t} + K_t = W_t \;\; N_t \;\; + \Pi_t + r_{K,t} K_{t-1} + \left(\frac{S_{hd,t} B_{t-1}^f + B_{t-1}}{P_t}\right) \tag{22}$$

where $P_{h,t}$ and $P_{f,t}$, respectively, denotes domestic price of home and imported consumer goods. Household facing exchange-rate risk ω_t in foreign asset market has access only to imperfect international asset market. Note that foreign bond B_t^f is denominated in U.S. dollar. Thus, the nominal exchange rate between home currency and the U.S. dollar is considered. Solving for the utility maximization problem gives us the marginal rate of substitution between works and consumption in (23), intertemporal substitution of consumption in (24), and uncovered interest rate parity in (25).

$$\left(N_t^i\right)^{\chi}\left(C_t^i - bC_{t-1}^i\right)^{\sigma} \mathrm{u}_t^N = W_t^{MRS} \tag{23}$$

$$\frac{\left(C_t^i - bC_{t-1}^i\right)^{-\sigma}}{P_t} \mathrm{u}_t^C = \beta(1 + r_t)\frac{\left(E_t C_{t+1}^i - bC_t^i\right)^{-\sigma}}{E_t P_{t+1}} E_t \mathrm{u}_{t+1}^C \tag{24}$$

$$S_{hd,t} = E_t S_{hd,t+1}\left(\frac{1 + r_t^{us}}{1 + r_t}\right)\omega_t \tag{25}$$

$P_t \left(= \left[\gamma P_{h,t}^{1-\varphi} + (1-\gamma) P_{f,t}^{1-\varphi}\right]^{1/(1-\varphi)}\right)$ is the utility-based consumer price index (CPI).

Since household is a monopoly supplier of differentiated services, nominal wage is set in Calvo-style, which results in nominal wage inflation dynamics as what follows:

$$\pi_t^w = \left\{\frac{\gamma_w}{1+\theta_w \beta \gamma_w}\right\}\pi_{t-1}^w + \left\{\frac{\beta}{1+\theta_w \beta \gamma_w}\right\} E_t \pi_{t+1}^w + \lambda_w\left(\widehat{w}_t^{MRS} - \widehat{w}_t + \mathrm{u}_t^w\right) \tag{26}$$

where $\lambda_w = \frac{(1-\theta_w)(1-\theta_w \beta)}{\theta_w(1+\theta_w \beta \gamma_w)}$. The parameter θ_w denotes wage stickiness, and γ_w is wage indexation. u_t^W is i.i.d wage markup shock. Note that nominal wage inflation responds positively to the wedge between wages demanded by optimizing household and marginal product of labor.

2.5. Trade balance, total value added, and monetary policy

We define trade balance as the balance between aggregate f.o.b exports and aggregate c.i.f imports.

$$\mathbb{T}_t = Y_{1h,t}^{jf} + \int_{j\in J} Y_{2h,t}^{jf}\, dj + \int_{j\in J} Y_{3h,t}^{jf}\, dj - M_{1f,t}^{h} - \int_{j\in J} M_{2f,t}^{jh}\, dj - \int_{i\in I} C_{f,t}^{ih}\, di \tag{27}$$

The aggregate value added of the economy ($\mathbb{Y}$), which corresponds to gross domestic product in data, can be defined as

$$\mathbb{Y}_t = C_t + I_t + \mathbb{T}_t \tag{28}$$

The model is lastly closed by considering a general form of monetary policy reaction as below:

$$r_t = \rho_R r_{t-1} + (1-\rho_R)\left(r_t^n + V_\pi \pi_{CPI,t} + V_{\mathbb{Y}} \widehat{\mathbb{Y}}_t + V_{\Delta S} \Delta s_{hd,t}\right) + \mathrm{u}_t^R \tag{29}$$

where $r_t^n\left(= \mathrm{u}_t^C + \sigma(u_t^I + \hat{a}_t)\right)$ is the natural rate of interest influenced by the efficient shocks, ρ_R measures the interest rate persistence, $V_\pi, V_{\mathbb{Y}},$ and $V_{\Delta S}$, respectively, indicates central bank's responsiveness toward variability in CPI inflation, aggregate demand variability, and rate of change in nominal exchange rates between home currency and U.S. dollar. u_t^R refers to i.i.d white noise to the conduct of monetary policy.

3. A Bayesian DSGE measurement

The model is estimated using Bayesian method. Bayesian estimation is principally about finding a set of parameters that maximizes the posteriors $p(\mathbb{X}|y, \mathcal{M})$ as a product of the likelihood function of the data derived from the model $p(y|\mathbb{X}, \mathcal{M})$ using Kalman filter and the prior belief on the probability distribution of the parameters $p(\mathbb{X}, \mathcal{M})$

$$p(\mathbb{X}|y, \mathcal{M}) = \frac{p(y|\mathbb{X}, \mathcal{M})p(\mathbb{X}, \mathcal{M})}{\int_{\mathbb{X}} p(y|\mathbb{X}, \mathcal{M})p(\mathbb{X}, \mathcal{M})d\mathbb{X}} \tag{30}$$

where $\mathbb{X}$ is a vector of model parameters, and $y(= \mathbb{R}^1, \dots, \mathbb{R}^T)$ is a set of observed data over T number of periods (see, for instance, Fernandez-Villaverde, 2010 for detailed discussion).

3.1. Data, priors, and posteriors

We study nine East and Southeast Asian economies, including Japan, the Republic of Korea, Hong Kong, Taiwan, Singapore, Malaysia, Thailand, Indonesia, and the Philippines, in addition to China. The selection is mainly motivated by the fact that these Asian economies are vertically most specialized in trade. While production sharing is equally observed in the rest of the world, the depth and complexity of production fragmentation and trade in East Asia is unparalleled. In a study of 79 countries, over 121 categories of goods within the period of 1967-2005, Amador and Cabral (2009) show that out of top ten vertically most specialized countries, eight are located in East Asia (see, also, Sawyer et al., 2010). Furthermore, Koopman et al. (2010) evidence that the positions of advanced and emerging Asia countries in global production chain of manufacturing sector are of variety ranging from Japan occupying the most upstream production to Korea and Taiwan at the midstream and China at the most downstream production (see, also, WTO and IDE-JETRO, 2011). All these make Asian economies become ideal sample for our investigation.

We utilize the quarterly time series from 2001 to 2008 as China's accession to World Trade Organization at the end of 2001 has fundamentally overhauled regional production sharing by substituting Southeast Asia as the destination for final assembly of intermediates shipped from Asian neighbours into consumer goods for exporting to the United States, Euro Area, and the rest of the world (see, for instance, Kim et al. 2011, and Athukorala, 2009). We categorize the nine Asian economies, excluding China (CN), into developing Southeast Asian economies (SEA4) which consists of Indonesia, Malaysia, Philippines, and Thailand, and advanced East Asian economies (EA5) for the rest. There are thus three two-country models to be estimated: SEA4-EA5 model, CN-EA5 model, and CN-SEA4 model. The name that appears first is treated as home country, while the following as foreign country.

Altogether nineteen macroeconomic observable series are used in estimation: GDP, consumption, investment, labor force, nominal short-term interest rate, nominal exchange rates between home currency and the U.S. dollar, PPI inflation, GDP deflator inflation, and CPI inflation for SEA4, EA5, and China in two-country setting, and the U.S. federal funds rate. All the quantity variables are deflated by respective deflators, and all data, except for the rates of inflation and interest, are logged and de-trended using Hodrik-Prescott filter with a smoothing parameter of

$\lambda = 1600$. We then construct cyclical observable series for SEA4 and EA5 weighted by time-varying fraction of national total trade over aggregate regional trade.

Table 1 reports the priors and probability distribution functions. We assume symmetric priors for both home and foreign country in estimation. Nonetheless, we allow different posteriors for price indexation and stickiness, share of imported intermediate inputs, home bias in consumption, monetary policy reaction functions, and standard deviation of structural shocks. We use Dynare 4.3 algorithms for model estimation, and adjust the number of Markov chains to ensure that estimates for mean and standard deviation within and across Markov chains are fairly consistent.

Note also that we have assumed uniform distribution for priors of which the true value is uncertain due to the lack of previous Bayesian studies on this region. This includes the share of imported inputs at midstream and downstream production, price stickiness, and the standard deviation of shocks. Equal probability is thus assigned for all potential parameter values within the theoretically coherent range. The priors for efficient shock persistence are in beta distribution, while the parameters in monetary policy reaction function, which theoretically must have positive values, are in gamma distribution with prior means follow the standard assumption.

----- [INSERT TABLE 1 HERE] -----

Table 2 reports the estimates of mode, mean and probability interval for selected parameters in SEA4-EA5 model, CN-EA5 model, and CN-SEA4 model. All structural shocks and parameters are nicely identified as evidenced by the proximity between posterior mode and mean which falls within the 90% probability interval (details are available upon request). Two parameter estimates with respect to intermediate inputs are particularly worthy for more ink. Firstly, Table 2 shows that China, Southeast Asia, and East Asia are tightly bound in the sense that midstream and downstream productions in these economies use heavily other's export of intermediate inputs.

Secondly, the estimated elasticity of substitution between domestic and imported intermediates is greater than one across models. This seems to be in contrast to existing empirical finding of inelastic substitution due to the complementarities between domestic and foreign inputs (see, for instance, Luong, 2011). What needs to be pointed out, however, is that such estimates are indeed about the elasticity of substitution between intermediate inputs *across different final outputs*, whereas elasticity of substitution between intermediates is *within a final output sector* in our context. More importantly, di Giovanni and Levchenko (2010) put forward a fact that elasticity of substitution is not empirically as important in bilateral business cycle comovement as Kose and Yi (2006), for instance, have speculated theoretically.

--- [INSERT TABLE 2 HERE] ---

4. Tracing value added, production fragmentation, and country upstreamness

Koopman et al. (2010) offer the most elaborated definition of vertical specialization till date by decomposing gross exports into domestic value added embodied in the exports of

(1) final goods and services absorbed by the direct importer;
(2) intermediates used by the direct importer to produce its domestically needed products;
(3) intermediates used by the direct importer to produce goods for third countries; and
(4) intermediates used by the direct importer to produce goods shipped back to source.

and foreign value added contained in domestic exports of intermediates and final goods. The latter is the earliest estimable definition of vertical specialization (VS) by Hummels et al. (2001).

4.1. Decomposing the value added of gross exports

We contribute to this literature by deriving an equation from the estimated model that corresponds exactly in definition to Koopman et al. (2010)'s decomposition. This exercise is useful in two mutually benefiting ways. First, it provides a macroeconomic perspective of vertical specialization that corresponds to micro evidence, paving the way for the computation of upstreamness of countries in global production sharing vis-à-vis trading partner. Second, doing so in turn makes international business cycle model attempting to explain the macroeconomic implications of vertical specialization more transparent in terms of its ability to account for different types of value-added trade.

To be compatible with the decomposition of Koopman et al. (2010), we break down gross exports to domestic value added embodied in exports DVA, "reflected domestic value added" $VS1*$, and foreign value added used in exports, VS:

$$\mathbb{x}_t = \sum_n DVA_{n,t} + VS1*_t + VS_t$$

where

$\sum_n DVA_{n,t} =$

$$\underbrace{\underbrace{\left\{1-\frac{M^h_{2f,t}}{Y_{3t}}\left(1-\frac{M^f_{1h,t}}{Y^f_{2t}}\right)\right\}Y^f_{3h,t}}_{(i)}}_{1} + \underbrace{\underbrace{\left(1-\frac{M^h_{0f,t}}{Y_{1t}}\right)\left(\frac{M^f_{1h,t}}{Y^f_{2t}}\right)Y^f_{2f,t}}_{(ii)} + \underbrace{\left(1-\frac{M^h_{1f,t}}{Y_{2t}}\right)\left(\frac{M^f_{2h,t}}{Y^f_{3t}}\right)\left(C^f_{f,t}+I^f_t\right)}_{(iii)}}_{2} \quad (31)$$

$$VS1*_t = \underbrace{\underbrace{\left(1-\frac{M^h_{0f,t}}{Y_{1t}}\right)\left(\frac{M^f_{1h,t}}{Y^f_{2t}}\right)Y^h_{2f,t}}_{(iv)} + \underbrace{\left(1-\frac{M^h_{1f,t}}{Y_{2t}}\right)\left(\frac{M^f_{2h,t}}{Y^f_{3t}}\right)Y^h_{3f,t}}_{(v)}}_{4} \quad (32)$$

$$VS_t = \underbrace{\left(1-\frac{M^f_{0h,t}}{Y^f_{1t}}\right)\left(\frac{M^h_{1f,t}}{Y_{2t}}\right)Y^f_{2h,t}}_{(vi)} + \underbrace{\left(1-\frac{M^f_{1h,t}}{Y^f_{2t}}\right)\left(\frac{M^h_{2f,t}}{Y_{3t}}\right)Y^f_{3h,t}}_{(vii)} \quad (33)$$

By adding up and simplifying Eqs. (31) to (33) together with transportation cost, we obtain the standard definition of gross exports, $\mathbb{x}_t \equiv \sum_{n=1}^{3} Y^f_{nh,t}$. It thus verifies our decomposition.

Component (1) in Eq. (31) indicates the domestic value added in exports of final goods, computed as the residuals between final output and imported intermediates in gross output. Because imported intermediates $M^h_{2f,t}$ comprise domestic value added embodied at earlier stage of foreign production, we add $M^f_{1h,t}$

as a share of gross foreign midstream output back into (1). Component (2) in Eq. (31) refers to domestic value added embodied in the export of domestic intermediates for foreign local needs at midstream $M^{f}_{1h,t}$ (item (*ii*)) and downstream level $M^{f}_{2h,t}$ (item (*iii*)) as a share of gross foreign output, respectively. Domestic intermediates production contains foreign value added as a result of using foreign intermediates of earlier stage. This value has to be deducted out. Note, however, that $M^{h}_{0f,t} = 0$ since upstream production uses only domestically owned inputs.

In contrast to Component (2), Component (4) in Eq. (32) indicates domestic value added embodied in the domestic intermediates used in foreign production for re-exporting back to source as intermediates (item (*iv*)) or final goods (item (*v*)). Likewise, foreign value added incorporated at earlier stage of production of domestic intermediates has to be taken into account. Last but not least, Eq. (33) informs us about the foreign content of domestic exports, after accounting for the domestic value added embodied in foreign intermediates.

Consider the definition of log-linearized variable: $\hat{x}_t = log\left(\frac{X_t}{\bar{X}}\right)$, where $\bar{X}$ refers to steady-state value. It implies that $X_t = \bar{X}e^{\hat{x}_t}$. By considering the relationship between c.i.f import and f.o.b export as in Eq. (15), our decomposition of gross export can be rewritten and rearranged as what follows for measurement

$$
\begin{aligned}
1 = {} & \underbrace{\left\{1-\kappa_3\left(1-\frac{\kappa_2}{(1+\bar{\tau}^f)e^{\hat{\tau}_t^f}}\right)\right\}\left(\frac{\bar{y}_{3h}^f}{\bar{\mathbb{X}}}\right)e^{\left(\hat{y}_{3h,t}^f-\hat{\mathbb{X}}_t\right)}}_{(i)} + \underbrace{\left\{\frac{\kappa_2^f}{(1+\bar{\tau}^f)e^{\hat{\tau}_t^f}}\right\}\left(\frac{\bar{y}_{2f}^f}{\bar{\mathbb{X}}}\right)e^{\left(\hat{y}_{2f,t}^f-\hat{\mathbb{X}}_t\right)}}_{(ii)} + \\
& \underbrace{(1-\kappa_2)\left\{\frac{\kappa_3^f}{(1+\bar{\tau}^f)e^{\hat{\tau}_t^f}}\right\}\left\{\left(\frac{\bar{c}_f^f}{\bar{\mathbb{X}}}\right)e^{\left(\hat{c}_{f,t}^f-\hat{\mathbb{X}}_t\right)}-\left(\frac{\bar{\iota}^f}{\bar{\mathbb{X}}}\right)e^{\left(\hat{\iota}_t^f-\hat{\mathbb{X}}_t\right)}\right\}}_{(iii)} + \underbrace{\left\{\frac{\kappa_2^f}{(1+\bar{\tau}^f)e^{\hat{\tau}_t^f}}\right\}\left(\frac{\bar{y}_{2f}^h}{\bar{\mathbb{X}}}\right)e^{\left(\hat{y}_{2f,t}^h-\hat{\mathbb{X}}_t\right)}}_{(iv)} + \\
& \underbrace{(1-\kappa_2)\left\{\frac{\kappa_3^f}{(1+\bar{\tau}^f)e^{\hat{\tau}_t^f}}\right\}\left(\frac{\bar{y}_{3f}^h}{\bar{\mathbb{X}}}\right)e^{\left(\hat{y}_{3f,t}^h-\hat{\mathbb{X}}_t\right)}}_{(v)} + \underbrace{\kappa_2\left(\frac{\bar{y}_{2h}^f}{\bar{\mathbb{X}}}\right)e^{\left(\hat{y}_{2h,t}^f-\hat{\mathbb{X}}_t\right)}}_{(vi)} + \\
& \underbrace{\left\{1-\frac{\kappa_2^f}{(1+\bar{\tau}^f)e^{\hat{\tau}_t^f}}\right\}\kappa_3\left(\frac{\bar{y}_{3h}^f}{\bar{\mathbb{X}}}\right)e^{\left(\hat{y}_{3h,t}^f-\hat{\mathbb{X}}_t\right)}}_{(vii)} \qquad (34)
\end{aligned}
$$

where $\kappa_n \equiv M_{n-1,f,t}^h / Y_{n,t}$.

4.2. Relation to existing models and measurements

How exactly important is the setting of three sequential stages of production with outputs of all chains allowed to be traded? Let us consider three different dominant models of international business cycle with trade: international real business cycle model of Raffo (2008), open-economy New Keynesian model of Smets and Wouters (2003), and dynamic Ricardian trade model of Yi (2003).

Raffo (2008) considers two-stage productions wherein domestic intermediates cross over borders for foreign final production, and vice versa, while final goods are non-traded. Smets and Wouters (2003) also employ two-stage production structure but allow both intermediates and final goods to be traded. Yi (2003) resembles our model the most in that final good is produced in three sequential stages. Both upstream and midstream outputs are tradable. Final goods, however, are not. By matching Eqs. (31) to (33) to the nature of trade of each model aforementioned, the value-added decomposition of gross export in these models can be written, respectively, as

International RBC of Raffo (2008): $\mathbb{x}_t = \underbrace{\left(1 - \frac{M_{1f,t}^h}{Y_{2t}}\right)\left(\frac{M_{2h,t}^f}{Y_{3t}^f}\right)\left(C_{f,t}^f + I_t^f\right)}_{(iii)}$

NK model of Smets and Wouters (2003):

$$\mathbb{x}_t = \underbrace{\left\{1 - \frac{M_{2f,t}^h}{Y_{3t}}\left(1 - \frac{M_{1h,t}^f}{Y_{2t}^f}\right)\right\} Y_{3h,t}^f}_{(i)} + \underbrace{\left(1 - \frac{M_{1f,t}^h}{Y_{2t}}\right)\left(\frac{M_{2h,t}^f}{Y_{3t}^f}\right)\left(C_{f,t}^f + I_t^f\right)}_{(iii)}$$

$$+ \underbrace{\left(1 - \frac{M_{1f,t}^h}{Y_{2t}}\right)\left(\frac{M_{2h,t}^f}{Y_{3t}^f}\right) Y_{3f,t}^h}_{(v)} + \underbrace{\left(1 - \frac{M_{1h,t}^f}{Y_{2t}^f}\right)\left(\frac{M_{2f,t}^h}{Y_{3t}}\right) Y_{3h,t}^f}_{(vii)}$$

Dynamic Ricardian trade model of Yi (2003):

$$\mathbb{x}_t = \underbrace{\left(1 - \frac{M_{0f,t}^h}{Y_{1t}}\right)\left(\frac{M_{1h,t}^f}{Y_{2t}^f}\right) Y_{2f,t}^f}_{(ii)} + \underbrace{\left(1 - \frac{M_{1f,t}^h}{Y_{2t}}\right)\left(\frac{M_{2h,t}^f}{Y_{3t}^f}\right)\left(C_{f,t}^f + I_t^f\right)}_{(iii)}$$

$$+ \underbrace{\left(1 - \frac{M_{0f,t}^h}{Y_{1t}}\right)\left(\frac{M_{1h,t}^f}{Y_{2t}^f}\right) Y_{2f,t}^h}_{(iv)} + \underbrace{\left(1 - \frac{M_{0h,t}^f}{Y_{1t}^f}\right)\left(\frac{M_{1f,t}^h}{Y_{2t}}\right) Y_{2h,t}^f}_{(vi)}$$

Obviously, many important genres of trade in domestic and foreign value added have been left out in these models, one way or another. The case of Raffo (2008) indeed put forward the argument of Hummels et al. (2001) that vertical specialization is more than just trade in intermediate goods. Vertical specialization involves export and import. Furthermore, as shown in Table 3 which we will discuss momentarily in next section, the missing domestic value added in intermediates export shipped back to source and foreign value added in domestic exports in Smets and Wouters (2003) and Yi (2003) are too critical to be ignored when measuring the country upstreamness in production sharing.

Constrained by two-country setting, our model is unable to account for domestic value added embodied in export of intermediates that will be re-exported to third country by direct importer after processing. Even so, relative to existing models our model permits the most comprehensive break down in matching Koopman et al. (2010)'s decompositions in such a way that $\sum_n DVA_{n,t}$ divided by gross export is the VAX ratio of Johnson and Noguera (2012a, 2012b); $VS1*_t$ corresponds partly to VS1 by Hummels et al. (2001) and exactly to VS1* in Daudin et al. (2011); and VS_t matches Hummels et al. (2001)'s VS in definition.

4.3. Identifying production fragmentation and upstreamness of countries

Based on the estimated κ_n, the calibrated "great ratios" for market-clearing condition of each stage and steady-state transportation cost, and data generated from the estimated model, Table 3 gives the numerical simulation on the models.

--- [INSERT TABLE 3 HERE] ---

Looking first at bilateral vertical specialization in gross export (VS), the estimates reasonably range from 20.11% to 34.97% on average over 2001Q1 to 2008Q4. Though not exactly comparable, this measure is in line with the estimates of multilateral vertical specialization of gross export obtained in Koopman et al. (2010) that range from 23.65% for EA5 excluding Singapore to 32.28% for SEA4 on average and 33.8% for China in 2004 for manufacturing sector, and of gross import obtained in Amador and Cabral (2009) that range from 20.3% for China to 24.5% for EA5 excluding Japan and 28.9% for SEA4 excluding Indonesia in between 2001-2005.

VS ratio, however, is imprecise as a measure of production fragmentation. Suppose country A produces only at downstream for final goods export with intermediates entirely imported from abroad. In contrast, country B fragments both midstream and downstream production with about half of the intermediates imported. Vertical specialization as a share of gross export for country A is equivalent to country B despite the fact that the latter has more fragmented production chains. VAX ratio proposed by Johnson and Noguera (2012a, 2012b) is more straightforward intuitively as a measure of production fragmentation.

Measured as domestic value added to export ratio, if export contains no imported intermediates, which implies the absence of production fragmentation, VAX ratio shall be 100%. In other words, as Johnson and Noguera (2012b) nicely put forward, the ratio declines when foreign intermediates are used in final goods export to direct importer (*(i)* in Table 3) and when intermediates exported are used as intermediates for local needs (*(ii)* and *(iii)*). Back-and-forth trade in intermediates made possible by production fragmentation also multiplies gross export more than proportionally than value added, depressing the ratio further.

This said, by turning to bilateral VAX ratio, Table 3 clearly shows that production in advanced East Asia economies has been vertically more fragmented than Southeast Asia economies (22.85% versus 72.54%) and China (25% versus

59.13%) on average. In the case of China and Southeast Asia, China is slightly ahead of Southeast Asia (43.08% versus 52.29%).

Decomposing gross exports into domestic and foreign value added facilitates the construction of an index that helps us to trace the upstreamness of a country within the global production sharing. Intuitively, for countries lying at upper stream of the production sharing, intermediate exports used by foreign importer are more likely to be shipped back to home for further processing. As a result, reflected domestic value added in the gross exports of countries at upstream end shall be more than proportional to foreign value added in its gross exports.

In the spirit of Koopman et al. (2010), we thus propose an upstreamness index computed as home country's log ratio of $VS1*$ to VS in gross exports.

$$U_{\frac{VS1*}{VS}} = ln\left(1 + \frac{VS1*}{\mathbb{x}_t}\right) - ln\left(1 + \frac{VS}{\mathbb{x}_t}\right) \quad (35)$$

Unsurprisingly, Table 3 shows that East Asia economies with index more than one stay at upper chain of production as compared to Southeast Asia and China. This largely confirms the findings of Kim et al. (2011), Koopman et al. (2010) and Athukorala (2009), for instance, that Japan lies upstream in the production chain by providing intermediate inputs and China lies downstream in the production chain by using imported intermediate inputs to provide final goods to the world, while other Asian economies, including Hong Kong, Korea, Taiwan, Malaysia, and Philippines, lie in between.

What make our story interesting is that both China and Southeast Asia lie at downstream in their bilateral interaction. This suggests that while China complements advanced East Asian economies as absorber of the latter's capital and intermediate goods, China instead competes head-to-head with Southeast Asia at final goods market (see, for instance, Haltmaier et al., 2007 and Eichengreen et al., 2007).

5. Does production upstreamness matter for shock propagation?

When foreign intermediates are as heavily used and productions are as fragmented and linked as Table 3 has shown, one expects business cycles of these economies to be more synchronized. As a matter of fact, di Giovanni and Lechvenko (2010) convincingly find that vertical trade is a determinant too important to be dispensed with to bilateral business cycle comovement. He and Liao (2012), Moneta and Ruffer (2009), and Shin and Wang (2003), to name just few, have found increasingly synchronized business cycles in Asia made possible by intra-industry trade. Figure 2 that compares bilateral cross correlation of simulated data with the actual series across three estimated models vividly illustrates this point. These economies comove tightly over the periods of 2001 and 2008, wherein bilateral export and import are most synchronized contemporaneously, followed by gross domestic product and consumption. And our estimated model of production fragmentation and vertical trade is able to replicate the business cycle comovement, though not perfectly.

--- [INSERT FIGURE 2 HERE] ---

Too often business cycle synchronization made possible by trade integration has been viewed as the underlying condition for the formation of monetary union. But business cycle synchronization doesn't necessarily imply symmetric responses toward macroeconomic shocks. While business cycles of two countries that are vertically linked in production and trade heavily with each other comove over an interval of period in the face of mixed variety of shocks, they may respond asymmetrically toward an identical shock. In fact, the seminal Bayoumi and Eichengreen (1994) have long pointed out that "output comovements are not the same as shocks." Even studies attempting to distinguish common from country-specific shock confound disturbances and responses. It is the latter, we believe, that should be further shed light in the discussion of macroeconomic interdependence.

Consider a 1% increase in the innovation of total factor productivity (favorable supply shock). We take stock on the dynamic response of aggregate value added (GDP) of each region toward both common – by assuming that home and foreign TFP shock are perfectly correlated – and regional-specific TFP shock, as shown in Figure 3. Vertical reading of the region indicates place in where shock originates, whereas horizontal reading refers to the responses. As far as idiosyncratic shock is concerned, favorable China's TFP shock lifts up GDP of East Asia, though marginally, that lies upstream but not of Southeast Asia that lies downstream in bilateral production fragmentation.

To the contrary, positive shock to Southeast Asian TFP that expands its own GDP marginally prospers thy Chinese GDP that stays equally with SEA4 at downstream but not that of East Asia that stays upstream. It is puzzling to find out that favorable shock to East Asian TFP expands Chinese but not Southeast Asian GDP, though both are positioned at downstream for East Asia in production sharing. This pattern turns out to be robust even when TFP shocks to China and Southeast Asia are perfectly correlated with East Asian TFP shock. It should be noted too that when TFP shock originates in downstream China, to which the rest are perfectly correlated, it is benign to all regardless of the position in production sharing. Puzzling enough, this is not the case when TFP shock originates in downstream Southeast Asia.

Having said that, based on the case of China-East Asia, we can still make an inference, though with caution, that when efficient supply shock strikes, responses of countries positioned at different stages of production that complement each other tend to be synchronized. Nonetheless, for countries staying at downstream, one's expansion may or may not come at the expense of another.

--- [INSERT FIGURE 3 HERE] ---

Responses are identical, however, regardless of the position in production sharing, when facing demand shock. Figure 4 illustrates dynamic response of GDP when there is 1% negative shock to the innovation of preference. GDP of all regions declines as a consequence. Still, production upstreamness leaves a mark on the pattern of responses. When shocks originates in the downstream China or Southeast Asia, to which East Asian preference shock is correlated, response of the upstream East Asia becomes larger. To the contrary, if shock originates in the upstream East Asian preference, responses of the downstream China and Southeast Asia are larger only if the shock is idiosyncratic. For countries that stay equally at downstream, the pattern of response is not conclusive. In particular, Chinese GDP falls to greater extent if shock to Southeast Asian preference is idiosyncratic. Quite the opposite, the magnitude of contraction in Southeast Asian GDP is stronger if shock to Chinese preference is correlated with its own.

--- [INSERT FIGURE 4 HERE] ---

Such distinct pattern of responses can also be found in the case of rising transportation cost. Figure 5 illustrates the dynamic response of GDP in the face of 1% increase in the innovation of transportation cost. Identical to the case of negative demand shock, regardless of the position in production sharing, rising transportation cost disrupts back-and-forth trade in intermediate goods and final goods, pushing GDP of all countries in production sharing down the cliff. Likewise, the magnitude of response depends where the country lies in the production sharing and the nature of shock. For shock originated in downstream China and Southeast Asia, GDP of the upstream East Asia falls to larger extent when its own transportation cost is also rising jointly.

--- [INSERT FIGURE 5 HERE] ---

5.1. Relation to empirical literature on great trade collapse and vertical specialization

What we have found in the role of vertical specialization and production upstreamness in shock propagation, especially for the case of East Asian and China when facing negative preference shock, corroborates the existing findings on the recent great trade collapse and vertical specialization. Levchenko et al. (2010), for instance, evidence that downstream vertical linkages play a role in the reduction in international trade, which in turn, contributes to the collapse in world aggregate value added. In particular, goods that are used intensively as intermediates for other countries experienced larger percentage drops in imports and exports. In other words, countries that lie at upper stream of production tend to be affected more severely than the downstream countries in the face of negative demand shock.

Another work by Bems et al. (2010) uncover both intermediate and final exports from Japan fall by more than exports from China, despite the fact that the United States is a bigger direct importer for China than Japan. Put in our context, the ripples of negative demand shock originated in extra-regional country must first arrive at the downstream China and to some extent the upstream East Asia which also exports final goods in a production sharing. "Third-country shock" is akin to common shock in our model with origins in China. The pattern of responses of GDP of China and East Asia toward negative demand shock shown in Figure 4 thus fits this piece of evidence, too.

The intuition is straightforward. Because the upstream East Asia involves more intensely in production sharing with multiple back-and-forth import and export of intermediates, evidenced by higher domestic value added embodied in intermediates export shipped back to East Asia for further processing at midstream level vis-à-vis China (30.73% versus 7.86%) and Southeast Asia (39.05% versus 0.37%) in Table 4, common shock hits East Asia harder[3].

6. CONCLUSION

This paper is part of the literature on the measurement of production fragmentation and trade in value added. But contrary to the admirably microscopic approach in empirical research, this paper takes up the challenge through a Bayesian estimated New Keynesian model expanded to feature three sequential production stages. Outputs of all stages are tradable. The estimated gross exports from this expanded New Keynesian model can then be broken down into domestic and foreign value added that match exactly the most comprehensive classifications of trade in value added available in empirical literature.

The usefulness of this macroeconomic approach is twofold: relevancy and consistency. On one end, it makes a model attempting to explain the macroeconomic

[3] Wang and Whalley (2010) document the export performance of Japan, the Republic of Korea, Taiwan, Indonesia, Malaysia, Thailand, and China over the periods of May 2008 and December 2009 with which our story depicted in Figure 3 under common shock is consistent. For instance, in the case of the United State as direct importer, on simple average, month-to-month export performance of the advanced East Asian economies deteriorates the most by 20.98%, followed by the developing Southeast Asia at 12.64% and China at 3.7%.

implications of vertical specialization transparent in terms of its ability to account for the types of trade in value added, and thus provides a yardstick on how empirically relevant the model is. On another end, it is so convenient to proceed to the followed-up investigation on the macroeconomic implications of vertical specialization in theoretically and empirical coherent manner. We find that, for instance, responses of countries bound but positioned at different stages in production sharing tend to be synchronized even in the face of country-specific supply shock. And the magnitude of response toward common and country-specific shocks is shaped by the country upstreamness.

A limitation of two-country model is its inability to account for domestic value added embodied in export of intermediates that will be re-exported to third country by direct importer after processing. The role of third country can be important in trade dynamics of production sharing. United States and the Euro Area, for instance, are heavyweight extra-regional trading partners for East Asia through the door gate of downstream China with Japan and other emerging Asian countries occupying the upstream and midstream production. Setting up and estimating a multi-country model shall be the venue for next pursuit.

References

Amador, J., Cabral, S., 2009. Vertical specialization across the world: a relative measure. The North American Journal of Economics and Finance 20(3), 267-280.

Athukorala, P-C., 2009. The rise of China and East Asian export performance: is the crowding-out fear warranted? The World Economy 32(2), 234-266.

Bayoumi, T., Eichengreen, B., 1994. One money or many? Analyzing the prospects for monetary unification in various parts of the world. Princeton Studies in International Finance No. 76, Princeton, New Jersey.

Bems, R., Johnson, R.C., Yi, K.-M., 2010. Demand spillovers and the collapse of trade in the global recession. IMF Economic Review 58(2), 295-326.

di Giovanni, J., Levchenko, A.A., 2010. Putting the parts together: Trade, vertical linkages, and business cycle comovement. American Economic Journal: Macroeconomics 2(2), 95-124.

Daudin, G., Rifflart, C., Schweisguth, D., 2011. Who produces for whom in the world economy? Canadian Journal of Economics 44(4), 1403-1437.

Devereux, M.B., Engels, C., 2007. Expenditure switching versus real exchange rate stabilization: Competing objectives for exchange rate policy. Journal of Monetary Economics 54, 2346-2374.

Eichengreen, B., Rhee, Y., Tong, H., 2007. China and the exports of other Asian countries. Review of World Economics 143(2), 201-226.

Feenstra, R., 1998. Integration of trade and disintegration of production in the global economy. Journal of Economic Perspectives 12(4), 31-50.

Fernandez-Villaverde, J., 2010. The econometrics of DSGE models. SERIES: Journal of the Spanish Economic Association 1, 3-49.

Goldberg, L., Tille, C., 2008. Vehicle currency use in international trade. Journal of International Economics 76(2), 177-192.

Haltmaier, J.T., Ahmed, S., Coulibaly, B., Knippenberg, R., 2007. The role of China in Asia: engine, conduit or streamroller? International Finance Discussion Papers No. 904, Board of Governors of the Federal Reserve System.

He, Dong, Liao, W., 2012. Asian business cycle synchronization. Pacific Economic Review 17(1), 106-135.

Hummels, D., Ishii, J., Yi, K-M., 2001. The nature and growth of vertical specialization in world trade. Journal of International Economics 54, 75-96.

Johnson, R.C., Noguera, G., 2012a. Accounting for intermediates: Production sharing and trade in value added. Journal of International Economics 86(2), 224-236.

Johnson, R.C., Noguera, G., 2012b. Fragmentation and trade in value added over four decades. Unpublished manuscript, Dartmouth College.

Kim, S., Lee, J-W, Park, C-Y., 2011. Ties binding Asia, Europe and the USA. China & World Economy 19(1), 24-46.

Koopman, R., Powers, W., Wang, Z., Wei, S.-J., 2010. Give credit where credit is due: tracing value added in global production chains. NBER Working Paper No. 16426. NBER, Cambridge.

Lee, G.H.Y., Azali, M., 2012. Is East Asian an optimum currency area? Economic Modelling 29(2), 87-95.

Levchenko, A.A., Lewis, L.T., Tesar, L.L., 2010. The collapse of international trade during the 2008-09 crisis: In search of the smoking gun. IMF Economic Review 58(2), 214-253.

Luong, T.A., 2011. The impact of input and output tariffs on firms' productivity: Theory and evidence. Review of International Economics 19(5), 821-835.

Mandelman, F.S., Rabanal P., Rubio-Ramirez, J. F., Villan, D., 2011. Investment-specific technology shocks and international business cycles: An empirical assessment. Review of Economic Dynamics 14(1), 136-155.

Moneta, F., Ruffer, R., 2009. Business cycle synchronisation in East Asia. Journal of Asian Economics 20, 1-12.

Raffo, A., 2008. Net exports, consumption volatility and international business cycle model. Journal of International Economics 75, 14-29.

Ravn, M.O., Mazzenga, E., 2004. International business cycles: the quantitative role of transportation costs. Journal of International Money and Finance 23(4), 645-671.

Sawyer, W.C., Sprinkle, R.L., Tochkov, K., 2010. Patterns and determinants of intra-industry trade in Asia. Journal of Asian Economics 21(5), 485-493.

Shin, K., Wang, Y., 2003. Trade integration and business cycle synchronization in East Asia. Asian Economic Papers 2(3), 1-20.

Smets, F., Wouters, R., 2003. An estimated dynamic stochastic general equilibrium model of the Euro Area. Journal of the European Economic Association 1(5), 1123-1175.

Wang, J., Whalley, J., 2010. The trade performance of Asian Economies during and following the 2008 financial crisis. NBER Working Paper No. 16142, National Bureau of Economic Research.

WTO, IDE-JETRO, 2011. Trade Patters and Global Value Chains in East Asia: From Trade in Goods to Trade in Tasks. Geneva.

Yi, K.-M., 2003. Can vertical specialization explain the growth of world trade? Journal of Political Economy 111(1), 52-102.

Table 1
The priors for parameters and shocks

	Prior distribution		
	Probability distribution function	Mean	Standard deviation
Parameters			
Risk aversion coefficient σ	Uniform	1	0.577
Reciprocal of wage elasticity of labor supply χ_N	Gamma	2	1.000
Habit persistence b	Beta	0.7	0.100
Forward looking-ness of investment decision Λ	Uniform	0.5	0.289
Els btw. home and imported intermediate goods ϑ	Normal	1.5	0.500
Home bias in consumption γ	Beta	0.7	0.100
Share of imported materials at intermediate production κ_2	Uniform	0.5	0.289
Share of imported intermediate goods at final production κ_3	Uniform	0.5	0.289
Employment indexation γ_w	Uniform	0.5	0.289
Producer price indexation γ_{p2}	Uniform	0.5	0.289
Final goods price indexation γ_{p3}	Uniform	0.5	0.289
Intermediate export price indexation γ_{p2}^*	Uniform	0.5	0.289
Final goods export price indexation γ_{p3}^*	Uniform	0.5	0.289
Employment stickiness θ_e	Uniform	0.75	0.144
Producer price stickiness θ_{p2}	Uniform	0.75	0.144
Final goods price stickiness θ_{p3}	Uniform	0.75	0.144
Intermediate export price stickiness θ_{p2}^*	Uniform	0.75	0.144
Final export price stickiness θ_{p3}^*	Uniform	0.75	0.144
Policy inertia ρ_R	Beta	0.7	0.100
Policy response to inflation V_π	Gamma	1.5	1.000
Policy response to GDP fluctuation $V_{\mathbb{Y}}$	Gamma	0.125	0.050
Policy response to exchange rate variability $V_{\Delta S}$	Gamma	0.5	0.100
TFP shock persistence ρ_a	Beta	0.8	0.100
IST shock persistence ρ_I	Beta	0.7	0.100
Shocks			
Total factor productivity σ_a	Uniform	0.5	0.289
Investment-specific technology σ_I	Uniform	0.5	0.289
Labor supply σ_n	Uniform	0.5	0.289
Preference σ_c	Uniform	0.5	0.289
Producer price markup $\sigma_{\pi_{2h}}$	Uniform	0.5	0.289
Final goods price markup $\sigma_{\pi_{3h}}$	Uniform	0.5	0.289
Intermediate export price markup $\sigma_{\pi_{2h}^*}$	Uniform	0.5	0.289
Final export price markup $\sigma_{\pi_{3h}^*}$	Uniform	0.5	0.289
Transportation cost σ_τ	Uniform	0.5	0.289
Monetary policy σ_r	Uniform	0.5	0.289
UIPC σ_s	Uniform	0.5	0.289
U.S monetary policy σ_{ffr}	Uniform	0.5	0.289

Table 2

Selected posterior distributions forthe estimated two-region models, 2001Q1-2008Q4

	Southeast Asia (SEA4)				East Asia (EA5)			
	Mode	5%	Mean	95%	Mode	5%	Mean	95%
Parameters								
σ	0.293	0.251	0.307	0.367	0.293	0.251	0.307	0.367
γ	0.636	0.559	0.618	0.669	0.891	0.858	0.896	0.928
ϑ	1.374	1.354	1.402	1.447	1.374	1.354	1.402	1.447
Λ	0.954	0.919	0.963	1.000	0.954	0.919	0.963	1.000
κ_2	0.434	0.238	**0.378**	0.507	0.724	0.629	**0.797**	0.955
κ_3	0.199	0.110	**0.197**	0.277	0.579	0.415	**0.524**	0.628
θ_{p2}	0.751	0.708	0.732	0.754	0.724	0.649	0.688	0.728
θ_{p3}	0.883	0.868	0.883	0.899	0.889	0.876	0.891	0.906
θ_{p2}^*	0.907	0.864	0.895	0.926	0.505	0.500	0.529	0.558
θ_{p3}^*	0.712	0.650	0.693	0.732	0.726	0.671	0.712	0.764
	China (CN)				**East Asia (EA5)**			
	Mode	5%	Mean	95%	Mode	5%	Mean	95%
σ	0.601	0.499	0.637	0.787	0.601	0.499	0.637	0.787
γ	0.479	0.443	0.480	0.517	0.788	0.754	0.791	0.833
ϑ	1.476	1.468	1.490	1.514	1.476	1.468	1.490	1.514
Λ	0.922	0.846	0.905	0.971	0.922	0.846	0.905	0.971
κ_2	0.405	0.339	**0.411**	0.497	0.493	0.450	**0.548**	0.640
κ_3	0.999	0.932	**0.965**	1.000	0.733	0.583	**0.693**	0.812
θ_{p2}	0.849	0.824	0.842	0.859	0.797	0.781	0.802	0.825
θ_{p3}	0.931	0.902	0.922	0.940	0.925	0.914	0.923	0.931
θ_{p2}^*	0.715	0.644	0.708	0.761	0.746	0.726	0.783	0.837
θ_{p3}^*	0.729	0.705	0.733	0.759	0.784	0.761	0.781	0.805
	China (CN)				**Southeast Asia (SEA4)**			
	Mode	5%	Mean	95%	Mode	5%	Mean	95%
σ	0.916	0.812	1.020	1.209	0.916	0.812	1.020	1.209
γ	0.844	0.808	0.862	0.902	0.603	0.579	0.618	0.663
ϑ	1.592	1.519	1.559	1.603	1.592	1.519	1.559	1.603
Λ	0.927	0.861	0.920	0.991	0.927	0.861	0.920	0.991
κ_2	0.512	0.377	**0.518**	0.709	0.732	0.424	**0.610**	0.771
κ_3	1.000	0.901	**0.949**	1.000	0.637	0.597	**0.752**	0.919
θ_{p2}	0.656	0.623	0.657	0.694	0.567	0.513	0.563	0.611
θ_{p3}	0.935	0.927	0.941	0.954	0.856	0.835	0.855	0.874
θ_{p2}^*	0.745	0.664	0.744	0.813	0.648	0.523	0.643	0.732
θ_{p3}^*	0.715	0.677	0.707	0.739	0.555	0.500	0.522	0.546

Notes: (i) The posterior distribution is obtained using the Metropolis-Hastings sampling algorithm based on 4 parallel chains of 50,000 draws, of which the first half was discarded as burn-in. The average acceptance rate for each estimated model is as what follows: SEA4-EA5: 0.219; CN-EA5: 0.235; and CN-SEA4: 0.251. We impose identical posteriors for σ, ϑ, and Λ across regions.
(ii) SEA4 comprises Indonesia, Malaysia, the Philippines, and Thailand weighted by total trades.
(iii) EA5 comprises Japan, Hong Kong, Korea, Singapore, and Taiwan weighted by total trades.

Table 3

Measuring average value added in gross export, and production fragmentation and upstreamness

	Decomposition of value added in gross exports (%)							Connection with existing measures			Measure of Upstreamness
	DVA in direct final goods export	DVA in intermediates absorbed by foreign for domestic use: Midstream	DVA in intermediates absorbed by foreign for domestic use: Downstream	DVA in intermediates export shipped back to source: Midstream	DVA in intermediates export shipped back to source: Downstream	Foreign VA: Midstream	Foreign VA: Downstream	VAX	VS1*	VS	*U*
	(i)	*(ii)*	*(iii)*	*(iv)*	*(v)*	*(vi)*	*(vii)*				
SEA4-EA5											
Southeast Asia	7.374	35.793	29.369	0.373	6.983	19.733	0.376	72.536	7.355	20.109	0.366
East Asia	17.633	4.132	1.089	39.053	3.126	26.052	8.916	22.853	42.179	34.968	1.206
CN-EA5											
China	23.723	19.164	16.237	7.856	0.422	12.762	19.835	59.125	8.278	32.597	0.254
East Asia	11.426	7.761	5.754	30.731	11.781	23.656	8.891	24.941	42.512	32.547	1.306
CN-SEA4											
China	35.839	4.323	2.917	9.307	10.580	11.907	25.125	43.080	19.888	37.032	0.537
Southeast Asia	28.751	15.918	7.624	11.041	1.876	15.433	19.358	52.293	12.917	34.790	0.371

Notes: (i) As a share of gross exports, VAX refers to domestic value added proposed by Johnson and Noguera (2012a, 2012b), and is a sum of *(i)*, *(ii)*, and *(iii)*; VS1* is reflected domestic value added, defined in Daudin et al. (2011) and responds partly to Hummels et al. (2001), and equals *(iv)* + *(v)*; VS refers to foreign value added of domestic exports as defined by Hummels et al. (2001), and is the sum of *(vi)* and *(vii)*.

(ii) $U = \frac{VS1*}{VS}$.

(iii) SEA4 comprises Indonesia, Malaysia, the Philippines, and Thailand weighted by total trades.

(iv) EA5 comprises Japan, Hong Kong, Korea, Singapore, and Taiwan weighted by total trades.

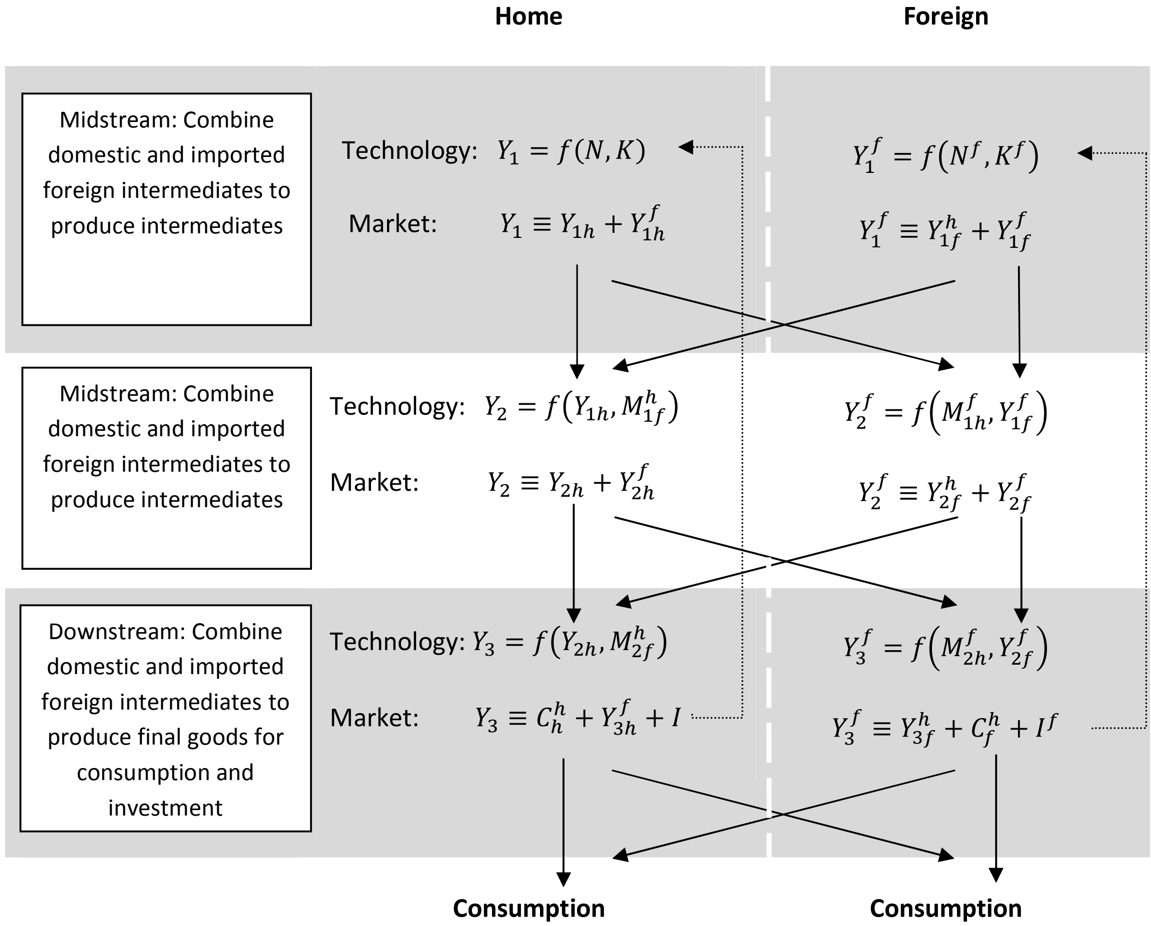


Figure 1. Structure of production and trade

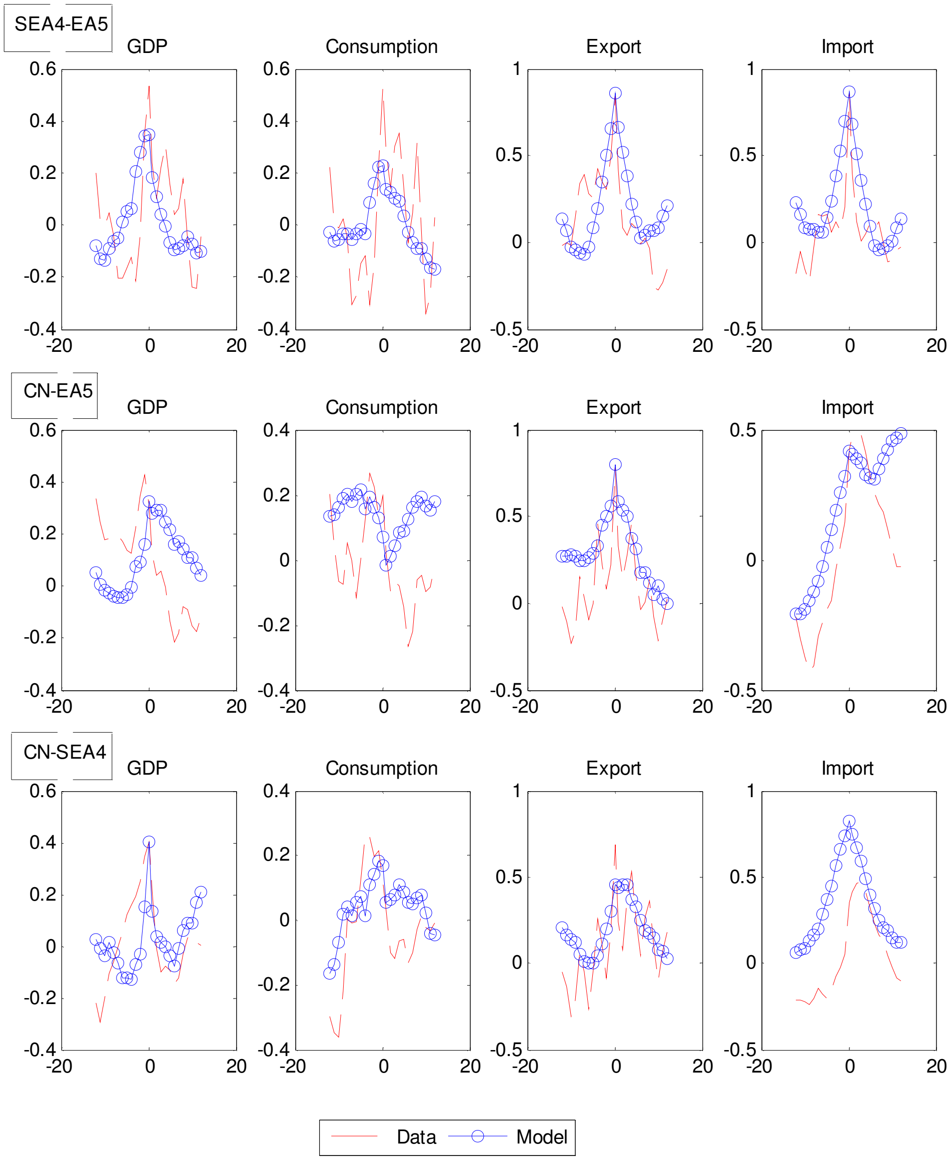
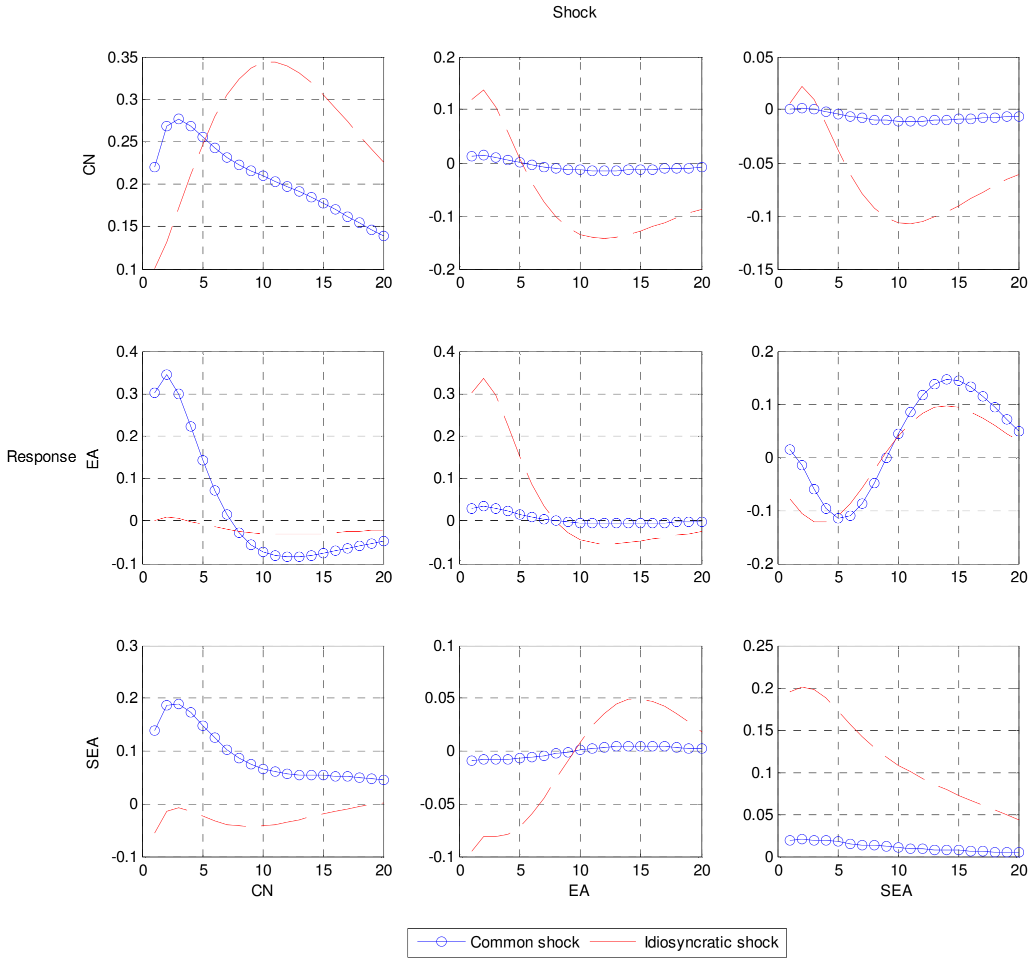
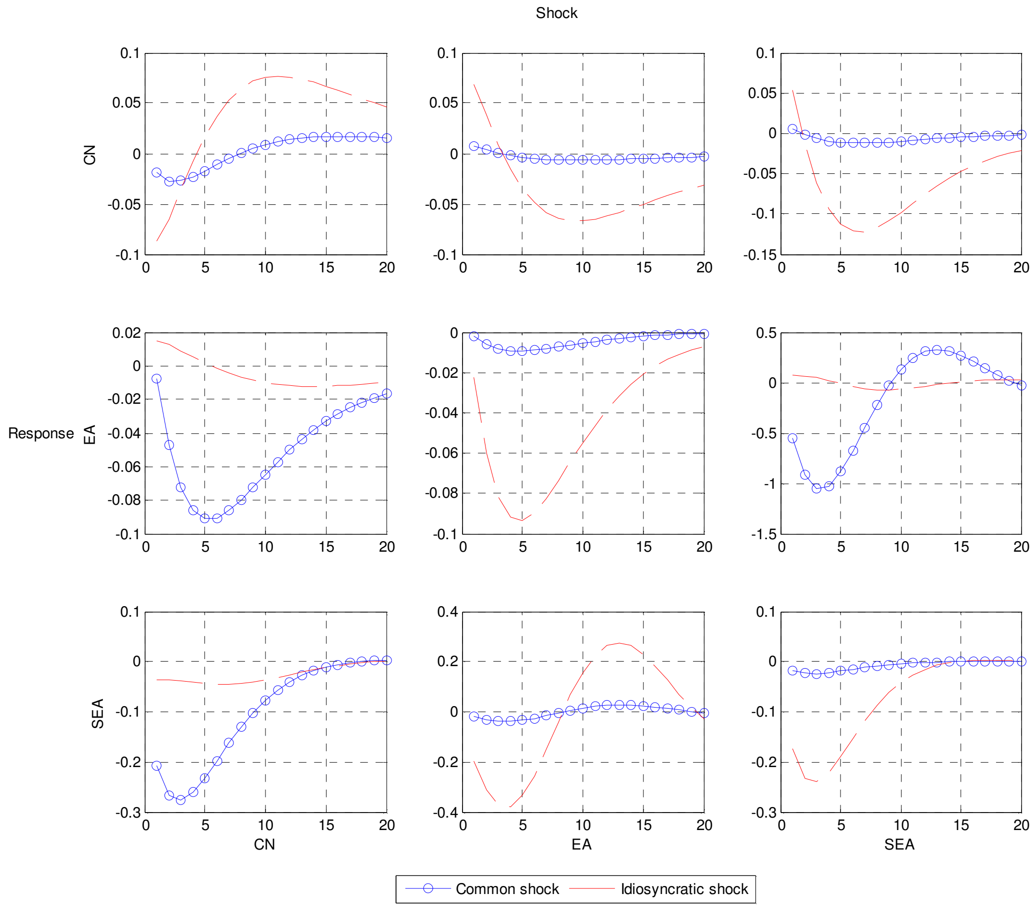


Figure 2. Cross correlation



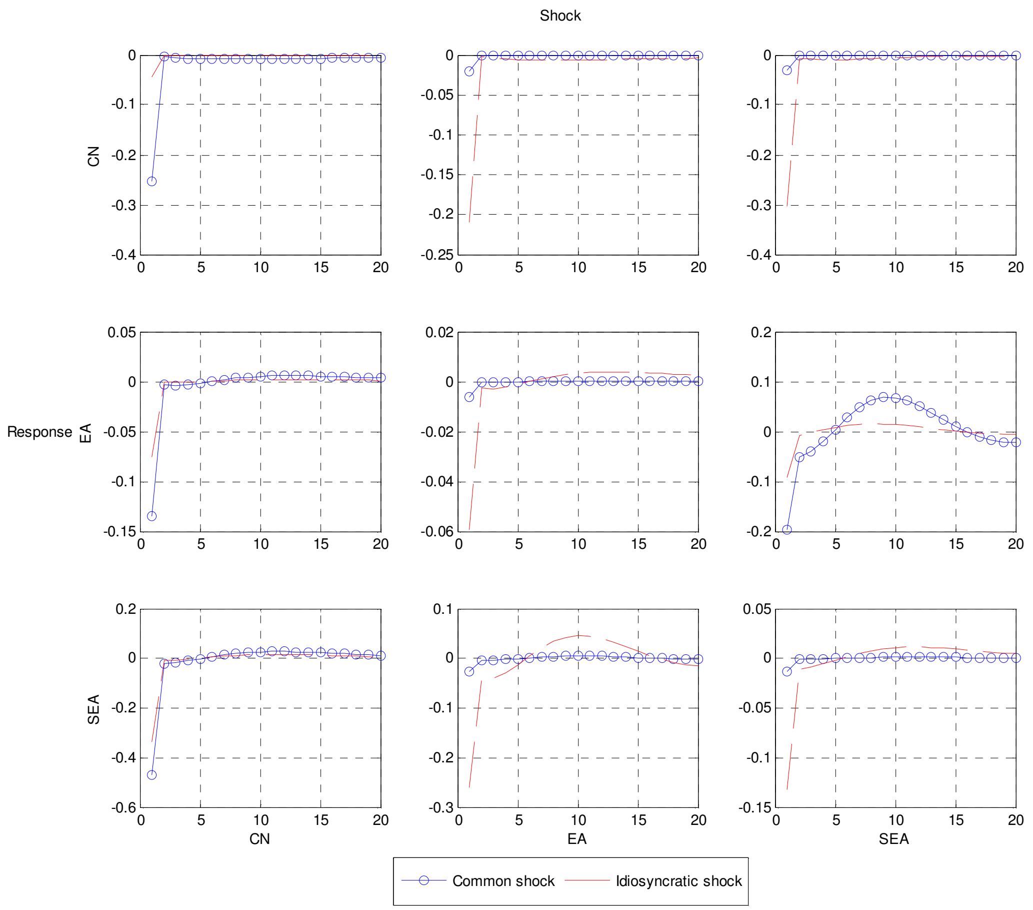
x-axis denotes period; y-axis indicates responses in percentage

Figure 3. Dynamic response of GDP toward common and idiosyncratic positive TFP shock.



x-axis denotes period; y-axis indicates responses in percentage

Figure 4. Dynamic response of GDP toward common and idiosyncratic negative preference shock.



x-axis denotes period; y-axis indicates responses in percentage

Figure 5. Dynamic response of GDP toward common and idiosyncratic positive transportation cost shock.