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The role of production fragmentation in international business cycle synchronization in East Asia

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Abstract

This paper analyzes factors contributing to the observed increase in international business cycle synchronization between eight East Asian developing countries and the major developed economies of Japan and the United States. To this end, a two-country Dynamic General Equilibrium (DGE) model is proposed which focuses on the role of production fragmentation among these countries. A key feature of the model is that it includes the trade in differentiated capital goods, which are added to the capital stock for production, and the technology embodied in these capital goods. The parameters of the model are calibrated using actual data of the countries included. Model simulations are conducted for two periods (1993-1997 and 1999-2005), before and after the Asian financial crisis, showing that the increase in business cycle synchronization can be attributed mainly to the growing fragmentation of production activities.

JEL classification: E32; F41

Key words: International business cycle synchronization; Fragmentation; Dynamic general equilibrium model

1 Introduction

As a result of economic and financial globalization, business cycles in countries around the world are becoming ever more synchronized. This can be most clearly seen in the impact of the financial crisis and economic slowdown in the United States since the summer of 2008 on economies around the world. This global slowdown, however, owes less to the global synchronization of business cycles as to the extraordinary magnitude of the United States financial crisis, and the literature on international business cycles suggests that, from a longer-term perspective, the global synchronization of business cycles is becoming somewhat less important, while the importance of regional synchronization among the highly integrated economies of North America, Western Europe, and emerging Asia appears to be increasing.[1] This "regional" synchronization is not necessarily limited to countries in close geographic proximity. It can also involve other groups of countries, which, for

[1] See, for example, International Monetary Fund (IMF) (2007).

example, are at the same stage of development (i.e., developed or developing) or are closely linked by trade and/or capital flows, regardless of their location.

Concerning emerging Asia, for example, recent research, such as that by the Asian Development Bank (ADB) (2007), has shown that business cycles in East Asia and major developed economies have become increasingly synchronized, and it is this synchronization of business cycles between East Asia and major developed economies that the present paper focuses on. In particular, the purpose here is to examine the mechanisms which are responsible for this synchronization and thereby to throw light on developments in other regions.

Regarding the factors underlying international business cycles, the roles of the trade in goods and of capital flows between the countries concerned have been widely discussed. However, the mechanisms through which this synchronization occurs have never been clarified, especially with regard to pairs of countries that include a developing economy.

With respect to developed countries, Frankel and Rose (1998) and Clark and van Wincoop (2001) showed that the extent of co-movements in the business cycle was positively correlated with trade intensity. Meanwhile, Miyagawa and Imamura (2003) arrived at a similar conclusion for developed economies (excluding Japan) based on a survey of the existing literature and their own analyses on the relationship between trade and international business cycles in the Asia-Pacific region. However, they found that trade could not explain the business cycle correlation between Asian developing countries and either Japan or the United States. Crosby (2003), also covering the Asia-Pacific region, arrived at results similar to those of Miyagawa and Imamura (2003) after conducting a regression analysis using the coefficient of correlation of business cycles as the dependent variable and the trade intensity index (the amount of trade between the partners concerned relative to their total trade) as the independent variable. What these various studies show is that pairs of developed countries closely linked by trade have a tendency to show a large degree of business cycle correlation, while pairs of developing countries do not. These findings raise the question of why the impact of trade on international business cycles differs so significantly for developed and developing economies.

The present paper argues that the structure of trade is an important element in this difference, and that the structure of trade rather than total trade volume is key in determining the extent of business cycle synchronization, particularly within a group of trading partners which includes developing economies. Preceding studies focusing on the influence of trade structure in business cycle synchronization include Shin and Wang (2004), Fidrmuc (2004), Kumamura (2006), Calderón et al. (2007), and Ng (2010). Shin and Wang (2004) as well as Fidrmuc (2004) focus on the role of intra-industry trade in the synchronizing of business cycles of East Asian and OECD countries. Ng (2010) examines whether pairs of countries with more extensive bilateral production fragmentation arrangements tend to have more closely correlated business cycles and found that bilateral production fragmentation has a contributing or positive effect in this correlation while the standard bilateral trade intensity index has a negative effect. Kumamura (2006) and Calderón et al. (2007) show that differences in the responsiveness of business cycle synchronization to trade intensities are explained by differences in the patterns of industrial structure specialization and bilateral trade. According to their results, in the case of trading partners each of which has a specialized industrial structure, growing trade leads to less synchronized cycles.[2] These are important findings that highlight the need to incorporate into the analysis intra-industry trade, and by extension, the role of production networks, which are responsible for a large part of intra-industry trade.

In East Asia, production networks have been formed through foreign direct investment by multinational enterprises (MNEs) which divide production processes into discrete steps located in different countries, resulting in the fragmentation of production. In these networks, each country specializes in a particular stage of the production process, and intermediate and capital goods are actively traded. This new type of trade may engender an international transmission of demand and technology in a quite different manner from the traditional Heckscher-Ohlin framework, in which different kinds of final goods are traded in line with the comparative advantages of each country.

Many of the above-mentioned studies focusing on the effect of trade in determining business cycle synchronization conducted regression analyses which include an indicator of business cycle correlation as the dependent variable and a trade intensity index as the independent variable. However, this approach has various drawbacks. One of these relates to the problem of endogeneity, since estimation results may be unstable owing to the choice of instrumental variables; another drawback, as pointed out by Shin and Wang (2004), concerns the evaluation of coefficients on trade intensity indexes. With regard to the latter point, consider two pairs of countries, say, A and B, and A and C, in which each pair has the same trade intensity. However, if the economy of country C is larger than that of country B, the demand spillover effects on country A (the coefficient on the trade intensity index) will be greater in the case of trade between A and C than it will be in the case of trade between A and B because the trade volume in the former case would be larger. Finally, the third and most serious drawback concerns the fact that regression analyses do not provide any theoretical underpinning for how intra-industry trade leads to business cycle co-movements.

Against this background, the present study attempts to provide such a theoretical underpinning by using a dynamic general equilibrium (DGE) model. Specifically, it proposes a two-country, three-good DGE model with trade in differentiated consumption and capital goods as well as non-tradable consumption.

The fragmentation of production, which this paper focuses on as a major contributing factor in business cycle synchronization, will be modeled as an exchange of capital goods among the countries concerned. The analysis here focuses on the developing economies of East Asia on the one hand and the developed countries of Japan and the United States on the other, with the former engaged in production activities and the latter conducting foreign direct investment in East Asia. The capital goods imported from Japan and the United States will be added to the East Asian countries' capital stock, which is used in the production of consumption and capital goods, some of which are exported to Japan and the United States. The DGE model proposed here also takes into account the technology embodied in capital goods, which is presumed to be completely different

[2] Using a structural vector autoregression (VAR) model, Abeysinghe and Forbes (2005) reveal that "indirect output-multiplier effects" are large and can transmit shocks in ways very different from those predicted from a bilateral trade pattern. These indirect output-multiplier effects are transmitted through a wide variety of cross-country linkages: flows of foreign direct investment, flows of mutual fund investment, flows of migrants and workers, trade competition in third markets, etc.

from the traditional form of technology, total factor productivity (TFP).

So far, international two-country DGE models have been used mainly to analyze the linkages between relatively symmetric developed economies, while in cases involving developing economies, small open economy models have been used with exogenously specified shocks in the terms of trade. In contrast, the present study employs a two-country model incorporating a group of East Asian developing economies (Korea, Taiwan, China, Singapore, Malaysia, Thailand, Indonesia, Philippines; hereafter referred to as East Asia) and a group of developed economies (Japan and the United States; hereafter referred to as Japan/United States) and calibrates the parameters of the model by using actual data for these countries without relying much on the parameters of preceding studies.

Mindful of the fact that East Asian economic environments changed significantly after the Asian financial crisis in 1998, the current study calibrates the parameters of the model and conducts model simulations for two periods, 1993-1997 and 1999-2005 separately, showing that the increase in business cycle synchronization can be attributed mainly to the growing fragmentation of production activities.

The remainder of this paper is organized as follows. Section 2 provides an empirical analysis of business cycle co-movements and the fragmentation of production activity in the sample countries. Section 2 also summarizes the preceding studies on the structural changes confronting East Asian economies since the financial crisis. Section 3 then reviews preceding studies that have developed DGE models to analyze international business cycles. Section 3 also presents this paper's model economies and discusses how the model is parameterized and solved. Section 4 presents the results, and Section 5 concludes.

2 The correlation of business cycles and fragmentation

2.1 Business cycle synchronization in East Asia and Japan/United States

The purpose of this section is to examine developments in business cycle synchronization between, and the fragmentation of production in, East Asia and Japan/United States. In examining business cycle synchronization, measurement of output co-movements is accomplished by collecting quarterly data on seasonally-adjusted real GDP for the eight East Asian countries and Japan and the United States. Business cycles are extracted using the Hodrick-Prescott (HP) filter. The correlation of business cycles for the forty-five pairs of countries is presented in Tables 1(1)(a) and 1(1)(b), with the former showing the correlations for 1999-2005 and the latter those for 1993-1997.[3] The

[3] The estimated periods are determined in accordance with those for the model simulation. See Section 3.4. Information on quarterly real GDP for China is available only from the first quarter of 2005. The only information available is the year-on-year rate of change. That is, the value of real GDP, which is needed for the HP filter, is unavailable. Accordingly, the filtering here is conducted using the World Bank's World Development Indicators (WDI), with the annual real GDP data for China converted into quarterly data using the interpolation method provided by EViews (Ver.6.0), which recovers high frequency series from low frequency data. To assess the appropriateness of the frequency conversion, the correlations of the same forty-five pairs of business cycles based on annual data are computed. The nominal GDP-weighted correlation between East Asia including China and Japan/United States is

correlation coefficients indicated by boldface in Table 1(1)(a) highlight those correlation coefficients that were higher in 1999-2005 than in the earlier period. Also, shaded correlation coefficients mean to be significant at 5 % or 1 % level. The two periods, omitting the year 1998, were selected to eliminate possible distortion of results owing to the irregular shock of the Asian financial crisis in that year.

-0.31 in the first period and 0.57 in the second period. The absolute values of these correlations are larger than those obtained based on quarterly data, but the basic conclusion that the correlation is greater in the second period remains the same.

Table 1(1)
Correlations of GDP movements across countries
(a) 1999-2005

	Korea	Malaysia	Indonesia	Philippines	Singapore	Taiwan	Thailand	China	Japan	United States
Korea										
Malaysia	0.44									
Indonesia	-0.19	**0.36**								
Philippines	**0.22**	**0.73**	**0.40**							
Singapore	**0.40**	**0.86**	**0.54**	**0.69**						
Taiwan	**0.47**	**0.87**	**0.27**	**0.73**	**0.87**					
Thailand	0.10	**0.56**	0.27	**0.57**	**0.49**	**0.66**				
China	-0.33	**0.31**	**0.53**	**0.54**	0.37	**0.46**	**0.64**			
Japan	**0.27**	**0.79**	**0.44**	**0.65**	**0.81**	**0.68**	**0.36**	**0.32**		
United States	**0.33**	**0.87**	**0.45**	**0.66**	**0.83**	**0.76**	**0.46**	**0.35**	**0.78**	

(b) 1993-1997

	Korea	Malaysia	Indonesia	Philippines	Singapore	Taiwan	Thailand	China	Japan	United States
Korea										
Malaysia	0.44									
Indonesia	0.29	-0.01								
Philippines	-0.04	-0.15	-0.09							
Singapore	0.21	-0.04	-0.15	-0.11						
Taiwan	-0.25	-0.12	-0.27	0.03	-0.22					
Thailand	0.83	0.32	0.48	-0.18	0.22	-0.17				
China	0.23	-0.15	0.10	-0.39	0.61	0.11	0.44			
Japan	0.07	0.38	0.16	0.32	-0.42	-0.23	-0.17	-0.50		
United States	-0.64	-0.48	-0.27	0.39	-0.12	0.57	-0.61	0.02	-0.10	

Sources: CEIC databases, World Development Indicators and author's calculations.
Note: GDP is on a per capita basis. Figures indicated by boldface in Table 1(1)(a) highlight correlations that are higher in 1999-2005 than in 1993-1997. Also, the shaded correlation coefficients mean to be significant at 5 % or 1 % level.

As shown in the table, the correlation increases significantly for almost all of the observations, indicating that business cycle synchronization is not restricted to some specific country-pairs but is a common trend in the region. Moreover, the overall correlation between business cycles in East Asia and Japan has changed from -0.13 in the earlier period to 0.40 in the latter period, while that between business cycles in East Asia and the United States has changed from -0.11 to 0.44. As a result, the correlation of business cycles with both Japan and the United States as the trade counterparty similarly increases from -0.12 to 0.43.[4] The observed increase in co-movements between business cycles in East Asia on the one hand and Japan and the United States on the other raises the question of what factors are responsible for bringing this about. Table 1(2) shows correlation coefficients of the two groups' main GDP components, namely private consumption and investment and net exports, calculated in the same manner as with the above GDP correlation. It is found that the correlation coefficient of private investment increases most between the two periods (-0.43 to 0.42).[5]

Table 1(2)
Correlations of GDP, investment, consumption and net export between East Asia and Japan/United States

	1993-97	1999-2005
GDP	-0.12	0.43
Investment	-0.43	0.42
Consumption	-0.19	0.13
Net export	-0.13	-0.08

Sources: CEIC databases, World Development Indicators and author's calculations.

The argument presented here is that the fragmentation of production plays a major role. It is therefore useful to look at fragmentation in greater detail.

In this context, the state of fragmentation is represented by the trade in capital and intermediate goods. Fig. 1 depicts the trade intensity indexes for capital goods (including intermediate goods) for nine of the countries in our sample (Taiwan is excluded due to data limitations), where trade intensity indexes are calculated as the share of capital and intermediate goods traded among the nine countries divided by the same share of the two kinds of goods in the total trade.

(Insert Figure 1)

[4]These overall correlations were obtained by using the pair-wise correlations between the eight developing countries and either Japan or the United States from Table 1(1) and then calculating the average using nominal GDP as a weight.

[5]The correlations of GDP, investment, consumption and net export between East Asia and Japan are as follows (figures in parentheses are for 1999-2005 and those without parentheses are for 1993-97): -0.13 (0.40) for GDP, -0.44 (0.38) for investment, 0.14 (0.13) for consumption, and -0.11 (0.13) for net exports. The correlations between East Asia and the United States are as follows: -0.11 (0.44) for GDP, -0.40 (0.44) for investment, -0.39 (0.14) for consumption, and -0.16 (-0.17) for net exports.

An increase in the index indicates that trade in the two goods has intensified in the region. Fig. 1 shows that the intensities have increased for most countries since the late 1990s. With regard to the question to be examined in this paper, what is important about these trends is the possibility that such active production sharing affects economies in unprecedented ways through demand and technology spillovers.

2.2 Changes in economic environment after Asian financial crisis

As shown in the above section, the correlation of business cycles has increased significantly for almost all the pairs of countries in East Asia and Japan/United States since the late 1990s. During the same period, the trade in capital goods began to intensify in these countries as well. In the following section, a two-country DGE model is proposed focusing on the role in greater business cycle co-movements of production fragmentation as trade in capital goods becomes more active. The purpose here is to explore what effects the 1998 Asian financial crisis had on changes in the production process.

Devereux and Sutherland (2009) point out that 'financial globalization', or the simultaneous increase in stocks of gross external assets and liabilities in emerging economies, including East Asia, dates back to the crisis. In particular, East Asian countries have been accumulating large stocks of the United States treasury bills in their official reserve assets while receiving large inflows of foreign direct investment (FDI) and portfolio equity investments at the same time. With respect to official reserve assets, Aizenman and Marion (2003) and Aizenman and Lee (2007) reveal that the financial crisis in East Asia led to profound changes in the demand for such reserves because Asian countries began regarding them as a precautionary adjustment, reflecting their desire for self-insurance against exposure to sudden stops.[6]

The build-up of large, positive net external positions as well as large reserve assets instilled considerable confidence in the investment potential of these economies and played a role in triggering a large increase in the inflow of FDI in the 2000s. Fig. 2 shows the values of foreign exchange reserve and FDI stock in the sample eight East Asian countries. It is evident that the two show a similar increase especially after 2000. It is this large FDI inflow from Japan, the United States and other advanced countries that accounts for the expansion in production fragmentation networks on the East Asian side.

(Insert Figure 2)

It is possible that the trade structure would be forced to undergo changes once the trade is deeply integrated into production fragmentation networks. The structural changes can appear in deep parameters like elasticities of substitution between different kinds of goods and/or in the composition of traded goods. After integration into the production network, each firm should

[6]IMF (2008) conducted the empirical analysis to explain the determinants of the current account balances (a flow of net external assets) of East Asian countries and concluded that a large part of their external balances were explained by their experience of the financial crisis and not by the standard factors that have been highlighted in the literature as important determinants of current account balances, i.e., the government balance, youth and old-age dependency ratios, growth opportunities, initial income level and so forth.

introduce specific capital equipment for producing specific products, and in that case, the traded capital goods can become necessities. As a result, the elasticities of substitution between those goods imported by the firm and other goods should be low. It is due the possibility for such structural changes that this study calibrates the parameters of the model and conducts model simulations separately for two periods, namely 1993-1997 and 1999-2005.

Other studies focusing on the changes in business cycle correlation between East Asia and developed economies (Japan, the United States and Europe) after the Asian financial crisis include ADB (2007) and Moneta and Rüffer (2009). ADB (2007) argued that the inter-regional correlation of business cycles between East Asia and developed economies can be attributed to significant export-led growth (the demand spillover effects from advanced countries which import goods from East Asian countries) since the crisis. Moneta and Rüffer (2009) revealed that the business cycle synchronization among East Asian countries including Japan mainly reflects strong export synchronization.

With respect to other possible factors affecting business cycle co-movements between East Asia and advanced economies, Takeuchi (2011) employs the structural factor-augmented vector autoregression (FAVAR) method to analyze factors affecting the business cycles of sixteen economies, including the seven major developed and nine East Asian countries, and found that the exchange rate policies of East Asian countries aimed at maintaining currency stability relative to the U.S. dollar have no longer been a common factor affecting business cycles in both regions since 2000 because these policies have been changing, and exchange rates have been relatively volatile since the Asian financial crisis. Takeuchi (2011) also found that financial shocks occurring in monetary policies affect only advanced economies and do not have spillover effects in East Asian countries.

2.3 Bilateral vs. triangular trade models

The DGE model the current study adopts is a bilateral model linking two mutually influencing trading groups, namely East Asia on the one hand and Japan/United States on the other. In the model, the United States is also regarded as a member of production fragmentation as is the case of Japan, and the two groups, East Asia and Japan/United States, influence each other.

In practice, however, the pattern of trade among East Asia, Japan, and the United States is often described as being triangular in that Japan exports mainly intermediate goods to East Asia while East Asia engages in assembly production and then exports final goods to the final consumption markets of the United States and Europe. In the triangular trade model, the United States and Europe are regarded as exogenous demand absorbers that are assumed to remain unaffected by Japan and East Asia. Therefore, it could be said that the model developed in this paper is not consistent with the traditional triangular trade model.

The traditional perspective usually describes the triangular trade between Japan, East Asia, and the United States and Europe as follows: (i) trade in intermediate goods between Japan and East Asia is increasing; and (ii) exports of final goods, particularly consumer goods, from East Asia to the United States and Europe are also increasing.[7]

[7] Exports from the United States and Europe to East Asia are rarely discussed in the literature. See, for example,

However, actual trade data show a different picture. Fig. 3, depicting the contribution of consumption goods and capital goods (including intermediate goods) to total growth in trade from 1995 to 2005 computed using the United Nation (UN) Comtrade database, reveals the following: (i) Capital and intermediate goods accounted for a large part of the growth in exports from Japan/United States to the East Asian countries; (ii), in East Asia's trade with Japan and the United States, capital and intermediate goods made the greatest contribution to export growth. These findings suggest that the United States does not specialize in the import of consumption goods, nor does Japan specialize in the export in intermediate goods.

The former finding suggests that the United States and Japan play similar roles in production networks with East Asia, i.e., the United States affiliates in East Asia, just like their Japanese counterparts, also import intermediate and capital goods from the home country and export final goods to the home country. Ando et al. (2006), using micro-data on Japanese and the United States MNEs located in East Asia, found that the affiliates of the two countries are quite similar in their sales and purchasing patterns.[8]

(Insert Figure 3)

In terms of the co-movement of business cycles in East Asia on the one hand and Japan and the United States on the other, this finding that East Asia is increasingly exporting capital goods to the two developed countries may be another explanation for greater GDP co-movements. These capital goods are used for investment both in Japan and in the United States.[9]

Consequently, it could be said that, with regard to trade and investment with East Asia, the United States plays much the same role as Japan does and should not be regarded as merely a final consumption market outside the fragmentation mechanism in East Asia. Against the background of these findings, the model developed and analyzed in the following sections is a two-country model consisting of one group comprising the East Asian countries and another comprising Japan and the United States.[10]

Ministry of Economy, Trade and Industry, Japan (2005).

[8]Ando et al. (2006) also argued that fragmentation activities in East Asia have been expanding in recent years, and this upward trend cannot be observed in other economic areas such as North American Free Trade Agreement (NAFTA) or Latin America.

[9]With regard to investment in East Asian countries, the Asian International Input-Output Table published by the Institute of Developing Economies, Japan External Trade Organization (IDE-JETRO), indicates that while the nominal GDP-weighted average share of domestically produced capital goods supplied to the domestic market dropped from 64 % in 1995 to 57% in 2000, the average share of domestically produced capital goods utilized in the domestic investment market increased from 47% to 61% in the same period. (The Asian International Input-Output Table is published once every five years, the latest version available being that for the year of 2000). Capital goods produced in East Asia have been supplied to economies outside the area and, at the same time, the demand arising from the production of capital goods in East Asia has contributed to stimulating investment in the region.

[10]The present study conducts a two-country DGE model simulation between a group of East Asian developing economies and a group of developed economies, not between two specific countries such as China and United States. This is because parameters calculated by using macro and semi-macro (industrial) data as described in the following section on calibration (3.4) can describe a country's entire international relationship with all other countries in the world as a whole but cannot describe its relationship with one other specific country. This is particularly so with the United States and Japan, which are relatively large countries. The United States and Japanese trade with China, which is the largest country in East Asia, only accounted for 14.2% of all trade for the United States and 20.4% of

3 Model

3.1 Background

The distinguishing features of the present study's two-country DGE model are as follows: (i) two kinds of tradable goods, capital and consumption goods, are included, and the imported capital goods are added to the capital stock for production in the two groups; (ii) countries are affected by two kinds of technologies, one being the traditional form of technology, TFP, and the other being the investment-specific technology embodied in the exchanged capital goods; (iii) the model distinguishes between non-tradable and tradable consumption goods; and (iv), as mentioned earlier, the present study employs a two-country model incorporating a group of East Asian developing economies in contrast to preceding studies in which international two-country DGE models have been used mainly to analyze the linkages between relatively symmetric developed economies.

Concerning feature (i), the number of tradable goods amounts to four because differentiated capital and consumption goods are exchanged between the two groups. After the pioneering study by Backus et al. (1992, 1994) and Ahmed et al. (1993), many of international business cycle models implemented final goods (consumption goods) and intermediate goods as tradable goods. Key characteristics of the present paper in this respect include the relatively large number of tradable goods and the incorporation of capital goods.

Implementing many different products produced in and traded among different countries is an effective way for model simulations to successfully deliver factual results.[11]

On the other hand, the trade in capital goods has also been highlighted recently as an important element in model building. Engel and Wang (2011) reveal the fact that a large portion of international trade is in durable goods, including both capital and durable consumption goods. They then propose a two-country two-sector model in which countries primarily trade durable goods such that the model matches the business cycle statistics on the volatility and co-movement of imports and exports relatively well. Another preceding study that implements the trade in capital goods is Boileau (2002).

Regarding the technology adopted in the current study's model, Boileau (2002) presented a two-country model focusing on the role of investment-specific technology embodied in internationally differentiated capital goods. This type of technology was investigated first by means of the closed model adopted by Greenwood et al. (1997, 2000), after which Boileau (2002) introduced the idea into the international business cycle model.[12]

all trade for Japan.

[11] The model developed by Backus et al. (1994) was a two-good international business cycle model. However, Kose and Yi (2001), applying the model to developed economies, found that it delivered counterfactual results. Meanwhile, Kose and Yi (2006) extended the model to consider three countries, not to increase the number of exchanged goods for modification.

[12] Greenwood et al. (1997, 2000) investigated the role of investment-specific technology in generating growth in the United States during the post-war period. Such investment-specific technology was represented by the decline in the relative price of capital goods and the increase in the capital goods-GDP ratio observed during the post-war period. They argued that investment-specific technology should be distinguished from the traditional Hicks-neutral form of technology.

In East Asia, production networks have resulted from foreign direct investment by MNEs based in advanced countries. In this process, technology transfers from MNEs to host countries are expected, and there are many surveys and empirical analyses which affirm the existence of these technology spillovers. One important channel through which this technology transfer takes place is believed to be the import of capital goods embodying technologies originating in the exporting countries.

The third feature of the present model, or the incorporation of non-tradable consumption goods, was first proposed by Tesar (1993) and Stockman and Tesar (1995) in opposition to the so-called consumption-output anomaly. These studies argued that, unlike the real economy, simulations often yield results which falsely suggest that consumption among countries is closely correlated while output is negatively correlated. We often observe the consumption-output anomaly because, in a model economy with a complete set of state-contingent markets, country-specific output risks should be pooled and domestic consumption growth should not depend heavily on country-specific income shocks. Popular approaches to modifying model simulation results introduce non-traded goods and/or taste shocks.

In reality, more than half of all consumption is of non-traded goods, including services. In the event that a positive technology shock were to increase the supply of such goods, people in the country could not smooth their consumption of goods perfectly by exporting them abroad. As a result, consumption could be weakly correlated across countries. Another preceding study implementing non-tradable consumption is McIntyre (2003).[13]

The second approach introduces taste shocks. Taste shocks raise consumption in one country without any change in the economic environment. Countries experiencing a taste shock would therefore borrow abroad to raise consumption. This would drive up interest rates in the foreign countries, in turn leading to reduced consumption by the foreign countries.

The above studies on international business cycle co-movements all focus on relatively similar industrialized countries. On the other hand, most studies on developing economies adopt a small open economy model in which the external economic factors are treated as exogenous. In order to reflect the major structural characteristics of developing economies, some papers modeled the exchange of primary and non-primary commodities (e.g., Mendoza, 1995; Kose and Riezman, 2001; Kose, 2002), while others attempted to reproduce co-movements by calibrating technological shocks specific to developing economies (e.g., Uribe and Yue, 2003; Aguiar and Gopinath, 2004).

3.2 The economic environment

The model used in analyzing co-movements of business cycles between East Asia and Japan/United States in this study is based on that developed by Boileau (2002) but modified to include non-tradable consumption. In the two-country model, the level of investment-specific technology corresponds to the cost of producing a new unit of final goods in terms of capital goods. Since this

[13] Recent models with heterogeneous firms also attack the consumption-output anomaly. Ghironi and Melitz (2005), a pioneering work in this vein, found that the anomaly can be substantially weaker, depending on the model.

approach allows us to use relative price data, it is comparatively easy to calibrate the technology parameters.

The environment consists of a two-country world economy in which each country is inhabited by a representative consumer and a representative firm. Hereafter, suffix 1 denotes the home and suffix 2 denotes the foreign country. The representative home consumer chooses consumption CT_{1t} and leisure l_{1t} to maximize the expected value of life time utility:

$$\max E_0 \sum_{t=1}^{\infty} \beta_1^t U(CT_{1t}, l_{1t}) \tag{1}$$

where the utility function is $U(CT_{1t}, l_{1t}) = (CT_{1t}^{\mu_1} l_{1t}^{1-\mu_1})^{\zeta_1}/\zeta_1$. Leisure is equal to the endowment of time T_{1t} minus hours worked n_{1t}, i.e.; $l_{1t} = T_{1t} - n_{1t}$. β_1 denotes the subjective discount rate with the relative risk aversion $1 - \mu_1\zeta_1$, the share parameter of consumption in the utility function being μ_1.

Consumption CT_{1t} consists of tradable goods c_{1t} and non-tradable goods cn_{1t}, which are aggregated using a constant elasticity of substitution (CES) aggregator as follows:

$$CT_{1t} = [(1 - \omega_{cn1})c_{1t}^{1-\rho_{cn1}} + \omega_{cn1} cn_{1t}^{1-\rho_{cn1}}]^{1/(1-\rho_{cn1})} \tag{2}$$

The elasticity of substitution between non-tradable and tradable goods is $\sigma_{cn1} = 1/\rho_{cn1}$. ω_{cn1} denotes the share parameter of non-tradable goods.

Similarly, home-made tradable consumption goods a_{1t} and foreign-made tradable consumption goods b_{1t} can be aggregated into tradable consumption goods consumed in home country using a CES aggregator as follows:

$$c_{1t} = [(1 - \omega_{c1})a_{1t}^{1-\rho_{c1}} + \omega_{c1} b_{1t}^{1-\rho_{c1}}]^{1/(1-\rho_{c1})} \tag{3}$$

The elasticity of substitution between home and foreign consumption goods is $\sigma_{c1} = 1/\rho_{c1}$. ω_{c1} denotes the share parameter of foreign goods.

Home country final goods, y_{1t}, are produced using capital stock k_{1t} and labor n_{1t}:

$$y_{1t} = s_{1t} k_{1t}^{\gamma_1} n_{1t}^{1-\gamma_1} \tag{4}$$

where s_{1t} denotes TFP and γ_1 is the capital distribution rate. Looked at from the supply side, y_{1t} can be allocated to non-tradable consumption goods, cn_{1t}, home goods consumed domestically, a_{1t}, home goods consumed abroad, a_{2t}, and investments, I_{1t}, i.e.:

$$y_{1t} = cn_{1t} + a_{1t} + a_{2t} + I_{1t} \tag{5}$$

Next, capital stock, k_{1t} is specified. In the closed model of Greenwood et al. (1997, 2000), the accumulation equation for the capital stock is expressed as $k_{t+1} = (1 - \delta)k_t + I_t z_t$, where z_t represents investment-specific technology, and δ is the rate of physical depreciation of the capital stock. In the two-county model developed in this paper, in which newly added investments (capital goods) come not only from the home country but also from the foreign country, the accumulation equation should be modified as follows.

Capital goods supplied by a domestic firm can be represented by

$$\varepsilon_{1t} + \varepsilon_{2t} = I_{1t} z_{1t} \tag{6}$$

where ε_{1t} will be used in the home country and ε_{2t} will be used in the foreign country.

The foreign firm also produces capital goods with the investment-specific technology, z_{2t}, expressed as $d_{2t} + d_{1t} = I_{2t} z_{2t}$. d_{1t} will be used in the home country and d_{2t} will be used in the foreign county. Therefore, in the two-country model, the capital goods, x_{1t}, which are newly added to the home country's capital stock, k_{1t}, are given by

$$x_{1t} = [(1 - \omega_{x1})\varepsilon_{1t}^{1-\rho_{x1}} + \omega_{x1} d_{1t}^{1-\rho_{x1}}]^{1/(1-\rho_{x1})} \tag{7}$$

The elasticity of substitution between home and foreign capital goods is $\sigma_{x1} = 1/\rho_{x1}$. ω_{x1} denotes the share parameter of foreign goods. In equation (6), the investment-specific technology, z_{1t}, used to produce capital goods can be interpreted as meaning that $1/z_{1t}$ corresponds to the cost of producing a new unit of capital goods in terms of final goods.

Next, installing new capital involves the following adjustment costs:

$$k_{1t+1} = F_{1t} - \delta_1 k_{1t}$$
$$F_{1t} = (x_{1t}^{\eta_1} + k_{1t}^{\eta_1})^{1/\eta_1} \tag{8}$$

If there are no adjustment costs ($\eta_1 = 1$), the stock accumulation equation simply becomes the commonly-used equation $k_{1t+1} = x_{1t} + (1 - \delta_1) k_{1t}$. However, in practice, there are various frictions, which means that newly added capital is unlikely to be used fully from the start. Under nonzero adjustment costs, η_1 should be less than 1.[14] As discussed in Hamermesh and Pfann (1996), the changes in the level of capital services generates net adjustment costs as a workforce's routine is disrupted and tasks need to be reassigned and restructured.

Finally, the stochastic process must be specified. This paper includes two types of technologies showing stochastic processes: TFP (s_1, s_2) and investment-specific technology (z_1, z_2). As discussed earlier, the latter affects economic growth through the production of more efficient capital goods. Home and foreign TFP and investment-specific technology are represented using the usual bivariate vector autoregressive (VAR) representation:

$$S_{t+1} = \Gamma_s S_t + \epsilon_{st+1} \tag{9}$$

[14] In general, the adjustment costs involved in installing new capital are specified as increasing and convex in x_t/k_t. Equation (8) can be transformed into $k_{t+1} = [\{(x_t/k_t)^\eta + 1\}^{\frac{1}{\eta}} - \delta] k_t$. Concerning the function of x_t/k_t, $\Phi(x_t/k_t) = \{(x_t/k_t)^\eta + 1\}^{\frac{1}{\eta}}$, $\Phi'(.) > 0$ and $\Phi''(.) < 0$. That is, the function $\Phi(x_t/k_t)$ is concave in x_t/k_t, indicating that the corresponding adjustment costs are convex in x_t/k_t.

$$Z_{t+1} = \Gamma_z Z_t + \epsilon_{zt+1} \tag{10}$$

where , $S_t = (\ln(s_{1t}), \ln(s_{2t}))'$, and , $Z_t = (\ln(z_{1t}), \ln(z_{2t}))'$. Γ_s and Γ_z are matrixes of coefficients and ϵ_{st+1} and ϵ_{zt+1} are vectors of mean zero normal random variables with contemporaneous covariance matrices Σ_s and Σ_z. TFP and investment-specific technology, as in Greenwood et al. (1997, 2000), are assumed to be independent of each other.[15]

It is assumed that there is a complete market for the international trade in financial assets. For simplicity, it is assumed that a home consumer owns the home firm and is allowed to participate in the international market for contingent claims. Consequently, the final goods market clearing conditions for the home country and the foreign country are:

$$p_{1t}y_{1t} = (p_{1t}cn_{1t} + p_{1t}a_{1t} + p_{2t}b_{1t}) + (q_{1t}\varepsilon_{1t} + q_{2t}d_{1t}) + [(p_{1t}a_{2t} + q_{1t}\varepsilon_{2t}) - (p_{2t}b_{1t} + q_{2t}d_{1t})] \tag{11}$$

$$p_{2t}y_{2t} = (p_{2t}cn_{2t} + p_{2t}b_{2t} + p_{1t}a_{2t}) + (q_{2t}d_{2t} + q_{1t}\varepsilon_{2t}) + [(p_{2t}b_{1t} + q_{2t}d_{1t}) - (p_{1t}a_{2t} + q_{1t}\varepsilon_{2t})] \tag{12}$$

In each equation, output $(p_{1t}y_{1t}, p_{2t}y_{2t})$, consumption $(p_{1t}cn_{1t}+p_{1t}a_{1t}+p_{2t}b_{1t}, p_{2t}cn_{2t}+p_{2t}b_{2t}+p_{1t}a_{2t})$, investment $(q_{1t}\varepsilon_{1t}+q_{2t}d_{1t}, q_{2t}d_{2t}+q_{1t}\varepsilon_{2t})$, and net exports $((p_{1t}a_{2t}+q_{1t}\varepsilon_{2t})-(p_{2t}b_{1t}+q_{2t}d_{1t}), (p_{2t}b_{1t}+q_{2t}d_{1t})-(p_{1t}a_{2t}+q_{1t}\varepsilon_{2t}))$ are all expressed at current prices, where p_{1t} and p_{2t} denote the prices of final goods and q_{1t} and q_{2t} denote the prices of capital goods. The sum of equation (11) and (12) yields the following equation:

$$\begin{aligned} p_{1t}y_{1t} + p_{2t}y_{2t} - (p_{1t}cn_{1t} + p_{2t}cn_{2t}) - (p_{1t}a_{1t} + p_{2t}b_{2t}) - (q_{1t}\varepsilon_{1t} + q_{2t}d_{2t}) \\ -(p_{2t}b_{1t} + p_{1t}a_{2t}) - (q_{2t}d_{1t} + q_{1t}\varepsilon_{2t}) = 0 \end{aligned} \tag{13}$$

The terms of trade for final goods, p_{2t}/p_{1t}, and for capital goods, q_{2t}/q_{1t}, are derived as in equation (14) and (15), respectively. As pointed out in the explanation of equation (6), the relative price of capital goods to final goods corresponds to the inverse of investment-specific technology (equation (16)):

$$\frac{p_{2t}}{p_{1t}} = \frac{\partial c_{2t}(b_{2t}, a_{2t})/\partial b_{2t}}{\partial c_{1t}(a_{1t}, b_{1t})/\partial a_{1t}} \tag{14}$$

$$\frac{q_{2t}}{q_{1t}} = \frac{\partial x_{2t}(d_{2t}, \varepsilon_{2t})/\partial d_{2t}}{\partial x_{1t}(\varepsilon_{1t}, d_{1t})/\partial \varepsilon_{1t}} \tag{15}$$

$$\frac{q_{1t}}{p_{1t}} = \frac{1}{z_{1t}}, \frac{q_{2t}}{p_{2t}} = \frac{1}{z_{2t}} \tag{16}$$

[15]Schmitt-Grohé and Uribe (2010) document that, in United States postwar quarterly data, TFP and the investment-specific technology are cointegrated.

3.3 Log-linearization

The model developed above is solved by linearizing the equations characterizing equilibrium around the steady state. First, the Bellman equation is presented:

$$\begin{aligned} J(k_{1t}, k_{2t}, z_{1t,} z_{2t}, s_{1t}, s_{2t}) = & \max_{cn_i, a_i, b_i, I_i, n_i} \{\alpha U_1(CT(cn_1, c_1(a_{1t}, b_{1t})), l(n_{1t})_{1t}) \\ & +(1-\alpha)U_2(CT(cn_2, c_2(b_{2t}, a_{2t})), l(n_{2t})_{2t}) \\ & +\lambda_1[y_1(z_{1t}, s_{1t}, k_{1t}, n_{1t}) - cn_{1t} - a_{1t} - a_{2t} - I_{1t}] \\ & +\lambda_2[y_2(z_{2t}, s_{2t}, k_{2t}, n_{2t}) - cn_{2t} - b_{2t} - b_{1t} - I_{2t}] \\ & +\beta_1 EJ_1([x(I_{1t})_{1t}^{\eta_1} + k_{1t}^{\eta_1}]^{1/\eta_1} - \delta_1 k_{1t}, z_{1t+1,} s_{1t+1}) \\ & +\beta_2 EJ_2([x(I_{2t})_{2t}^{\eta_2} + k_{2t}^{\eta_2}]^{1/\eta_2} - \delta_2 k_{2t}, z_{2t+1}, s_{2t+1}])\} \end{aligned} \quad (17)$$

where $J(.)$ is a value function and λ is a Lagrange multiplier to the constraint[16]. The first order conditions (FOC) include;

$$\alpha U_{1a_1} = (1-\alpha)U_{2a_2} = \alpha U_{1cn_1} = \lambda_1, \quad \alpha U_{1b_1} = (1-\alpha)U_{2b_2} = (1-\alpha)U_{2cn_2} = \lambda_2 \quad (18)$$

$$\begin{aligned} \alpha U_{1n_1}(CT_{1t}, l(n_{1t})_{1t}) &= -\lambda_1 y_{1n_1}(z_{1t}, s_{1t}, k_{1t}, n_{1t}) \\ (1-\alpha)U_{2n_2}(CT_{2t}, l(n_{2t})_{2t}) &= -\lambda_2 y_{2n_2}(z_{2t}, s_{2t}, k_{2t}, n_{2t}) \end{aligned} \quad (19)$$

$$\beta_i J_{iI_i}([x(I_{it})_{1t}^{\eta_i} + k_{it}^{\eta_i}]^{1/\eta i} - \delta_i k_{it}, z_{it+1,} s_{it+1}) = \lambda_i \quad ; i = 1, 2 \quad (20)$$

3.4 Calibration

In order to use the model developed in the preceding section to simulate business cycle co-movements in East Asia on the one hand and Japan and the United States on the other, some calibration is required. Given that the model simulation will be conducted for two different periods, from the first quarter of 1993 to the fourth quarter of 1997 and from the first quarter of 1999 to the fourth quarter of 2005, for comparison, the parameter values of the equations should also be estimated for each period.

[16] In equation (17), the time-invariant welfare weight α attached by the social planner is usually parameterized to be equal to the relative size of country 1. The economic size of the eight East Asian countries in terms of real GDP amounted to 54 % of the joint GDP of Japan and the United States in 1993-1997 and 67 % in 1999-2005. These figures are computed using real GDP data on a purchasing power parity basis available from the Penn World Table (Ver.6.1), Center for International Comparisons at the University of Pennsylvania. Meanwhile, α can be specified as a function of the relative size of consumption and some other variables in a steady state by using equation (18), i.e., $\alpha/(1-\alpha) = u_{2a_2}/u_{1a_1}$. This function is used to calibrate the share parameter of consumption μ included in the function by specifying other parameters including the welfare weight. See Section 3.4.

The second simulated period ends in 2005 and is not extended to 2006 and beyond (which would include the recent worldwide recession) due to data constraints resulting from the fact that one important data source (the Asian International Input-Output Tables) is available only for the years of 1995 and 2000.[17] However, as mentioned in the introduction, the aim of this paper is to analyze the region-based synchronization of business cycles which has been observed over a longer perspective before the recent global recession.

Some parameters are calculated as the GDP-weighted average of the parameter for each country comprising each group, respectively, not as the sum of member countries in each group. The main data sources for the calibration are the Asian International Input-Output Tables for 1995 and 2000, the World Bank's World Development Indicators, Penn World Table (Version 6.1) and the CEIC databases (CEIC Data Company Ltd.).[18]

To begin with, the elasticities of substitution between home and foreign tradable goods, σ_c and σ_x, and the elasticity of substitution between tradable and non-tradable consumption, σ_{cn}, are calibrated. Data for two different compared production, $g_1$and g_2, and the relative price of p_1 and p_2, are used to derive the elasticity of substitution $-\partial(g_1/g_2)/\partial(p_1/p_2)$ with $d\ln(g_1/g_2)$ as the dependent variable and $d\ln(p_1/p_2)$ as the independent variable.

A description of how these variables are derived for estimation purposes is presented below.

On the East Asian side, the prices of domestic capital goods are represented by System of National Accounts (SNA) deflators of fixed capital formation excluding residential investments. Based on the assumption that each country's export goods can be largely divided between consumption goods and machinery/equipment (the latter assumed to be capital goods), prices of tradable consumption goods in exporting countries are calculated by using macro export price indices, SNA deflators of fixed capital formation excluding residential investments, and the share of machinery/equipment in total export values. Data sources are International Financial Statistics (IFS) for export prices, the CEIC database for SNA deflators and Asian International Input-Output Tables (referred to hereafter as Asia IO) for the share of exported machinery/equipment.

Next, the prices of non-tradable consumption are derived. The data used are SNA private consumption deflators (CEIC database), the share of non-tradable consumption in total private consumption (Asia IO) and the prices of tradable consumption goods calculated as above. Non-tradable consumption in Asia IO are defined as the sum of (i) Electricity, gas and water supply (code 4 of 7 sectors industrial classification of Asia IO); (ii) Construction (code 5); (iii) Trade and transport (code 6); (iv) Services (code 7).

In the side of Japan and United States, the above mentioned deflators of three kinds of categories (capital and tradable consumption goods and non-tradable consumption) are all derived from each SNA statistics.

All the price indices for different countries are used to produce weighted averaged East Asia and Japan/United States price data. The weight adopted is each country's real GDP in the year

[17]The parameters for the 1993-1997 simulation are calibrated from the 1995 Input-Output Table, while those for the 1999-2005 simulation are from the 2000 Input-Output Table.

[18]The CEIC databases provide macroeconomic, industrial, and financial time-series data for China and other Asian countries.

2000.

Next, the volumes of import and domestic production are derived. The import values for each good are available from UN Comtrade database for East Asian countries as well as Japan and the United States. Imported consumption goods are calculated as the sum of food and beverages (code 1 of 1 digit classification by broad economic categories) and consumption goods nes (code 6). These annual data are converted to quarterly data by using the shares of quarterly GDP in each year's total GDP. That is, quarterly import series are derived as annual import data multiplied by the quarterly share of GDP. Next, quarterly import values are converted to volumes by using the other area's (the exporter's) price of tradable consumption goods. Volumes of imported capital goods are calculated as the same manner as tradable consumption goods. Capital goods correspond to the category of machinery and transport equipment in the UN Comtrade database (code 7 of 1 digit Standard International Trade Classification, Rev. 2), and the other area's (exporter's) capital goods prices are used to derive volumes.

Domestic production volumes for capital goods are obtained as SNA fixed capital formation data excluding residential investments for East Asia and Japan/United States. In Japan/United States, volume data for tradable consumption (goods) and non-tradable consumption (services) are also from SNA statistics. In East Asia, the procedures for obtaining domestic production volumes for the two kinds of consumption are as follows. First, as in the calculation of the tradable consumption deflator, the tradable consumption volume is derived based on the assumption that domestic production can be divided into consumption goods and machinery/equipment, which is assumed to be capital goods. Non-tradable consumption volumes in East Asia are obtained using total consumption volumes (SNA), the above-derived tradable consumption volumes and the share of non-tradable consumption in total consumption (Asia IO).

Prices and volume data are used to calculate the elasticity of substitution between domestic and imported capital goods, the elasticity of substitution between domestic tradable consumption and imported consumption goods and the elasticity of substitution between tradable and non-tradable consumption. An equation for estimating the elasticity of substitution can be derived by using an optimizing condition under which the marginal rate of substitution is equal to the price ratio between different goods. For example, the elasticity of import-home consumption good substitution ($\sigma_{c1} = 1/\rho_{c1}$ in equation (3)) can be obtained from the following equation: $\ln(a_{1t}/b_{1t}) = c - \sigma_{c1} \ln(p_{1t}/p_{2t}) + \varepsilon_t$, where the estimated parameter σ_{c1} is the elasticity.[19]

The three kinds of elasticities are all estimated via Generalized Method of Moment (GMM). Instrumental variables used here are international relative productivity comparing the two areas (in the case of domestic and imported production) and domestic intersectoral productivity comparing tradable and non-tradable industries (in the case of tradable and non-tradable consumption).

International and intersectoral productivity data are obtained from the Growth and Productivity Accounts database (EUKLEMS).[20] In East Asia, productivity data is available only for Korea,

[19]In the case of equation (3), the marginal rate of substitution between home-made tradable consumption goods, a_1 and foreign-made tradable consumption goods, b_1, is equal to $\partial b_{1t}/\partial a_{1t} = (\partial c_{1t}/\partial a_{1t})/(\partial c_{1t}/\partial b_{1t}) = (1-\omega_{c1})/\omega_{c1} * (a_{1t}/b_{1t})^{-(1/\sigma_{c1})} = p_{1t}/p_{2t}$.

[20]http://www.euklems.net/

so these data are used as representing East Asia's productivity as a whole.

In section 2.2, it is noted that the elasticity of substitution between domestic and imported capital goods may fall if the country is deeply integrated into production fragmentation networks. From Table 2, we can observe that elasticity does indeed decrease from the 1990s through the 2000s. The elasticity of substitution between domestic and imported capital goods falls in both East Asia and Japan/United States, or from 2.810 to 1.760 and 2.070 to 1.710, respectively.

Deardorff and Stern (1990) estimated the elasticity of import-home good substitution for different goods. According to their estimates using United States data for the year 1976, the elasticity was 2.110 for electrical machinery, 1.002 for nonelectrical machinery, and 3.585 for transport equipment. The average elasticity of these three kinds of goods, which largely corresponds to the elasticity of capital goods in the current study, was 2.239. In the case of consumption-related goods, the elasticity was 1.139 for agriculture, forestry, and fishery, 1.139 for foods, beverage, and tobacco, 1.147 for textiles, and 1.810 for leather products, etc.

The elasticity of substitution between tradable and non-tradable consumptions also decreases in both areas. Stockman and Tesar (1995) conducted a survey of the elasticity of substitution between tradable and non-tradable consumption goods obtained in preceding studies and carried out their own estimates using a sample of thirty developed and developing countries for the year 1975. They arrived at an estimate of 0.44, indicating a low elasticity of substitution between tradable and non-tradable goods. Moreover, they found that the elasticity was significantly higher for developing than for developed countries. Table 2 shows that (i) the elasticities are higher in East Asia compared to Japan/United States and (ii) in both areas, the elasticities in the 2000s are lower than those in the 1990s.

Next, the share parameters for non-tradable consumption goods, ω_{cn}, foreign consumption goods, ω_c, and foreign capital goods, ω_x, included in equation (2), (3) and (7) are all calculated from Asia IO.

Concerning capital productivity, y/k and the investment-capital stock ratio, x/k, the following method is applied. First, by using $y_k = \gamma * y/k = r$, where r is the real interest rate, capital productivity can be calculated by dividing the real interest rate by the capital distribution rate, γ. Next, by multiplying this capital productivity by the investment-GDP ratio, the investment-capital stock ratio is obtained. Investment-capital stock ratios are 0.024 (0.016) for East Asia and 0.003 (0.002) for Japan/United States. Real interest rates are assumed to be equal to the averaged real GDP growth rates in both periods for both groups. Henceforth, figures for 1993-1997 will be shown without parentheses and those for 1999-2005 will be shown in parentheses.

The physical depreciation of capital stock, δ, is assumed to remain unchanged for the two periods and is set as 0.025 for both groups. This figure is the same as that used in Backus et al. (1994) and Boileau (2002). As this parameter is not calibrated from actual data, a sensitivity analysis will be conducted concerning its role in the model in the next section.

The capital distribution rate, γ for Japan/United States is empirically calibrated as 0.460 for both periods, while the rate for the East Asian countries is 0.300 (0.350).

Table 2
The elasticities of substitution between domestic production and import for capital goods (σ_x) and tradable consumption goods (σ_c) and the elasticity of substitution between domestic tradable and non-tradable consumption (σ_{cn})

(1) East Asia		
	1993-97	1999-2005
σ_x	2.810	1.760
	[0.081]	[0.087]
σ_c	2.540	1.590
	[0.015]	[0.050]
σ_{cn}	0.404	0.370
	[0.059]	[0.118]
(2) Japan/United States		
	1993-97	1999-2005
σ_x	2.070	1.710
	[0.096]	[0.021]
σ_c	0.900	1.450
	[0.075]	[0.016]
σ_{cn}	0.230	0.104
	[0.066]	[0.053]

Sources: International Financial Statistics, CEIC databases, Asian International Input-Output Tables and author's calculations.
Note: The figures in square brackets are p-values.

The adjustment cost parameter, η, was 0.8 in Uhlig (1995),[21] and this value is used as a reference. This paper applies the method of Ravn and Mazzenga (2004), in which the parameter is calibrated such that the relative volatility of investment to output is approximately the same as the empirical relative volatility. Once the other parameters have been calibrated, the adjustment cost parameter is calibrated so as to deliver results that are quantitatively consistent with the empirical business cycle co-movements. The relative volatility of investment is then checked in the simulation.

As a result, the adjustment cost parameters are set to 0.500 (0.600) for East Asia and 0.600 (0.950) for Japan/United States. The corresponding relative investment volatility in the model simulation is 2.650 (4.140) for East Asia and 5.570 (5.070) for Japan/United States. The empirical values obtained for the relative investment volatility are 3.130 (4.380) for the former and 4.870 (4.610) for the latter.

The relative risk aversion, $1 - \mu\zeta$, is derived via GMM estimation. Following Hall (1988) and Vissing-Jøgensen (2002), the estimation adopts the difference in the logarithm of real consumption

[21] For a survey on adjustment costs, see Hamermesh and Pfann (1996).

as the dependent variable and the lagged real interest rate as the independent variable.[22] Based on the specification of the utility function in this study, the estimated parameter corresponds to $1/(1-\mu\zeta)$ (i.e., the intertemporal substitution elasticity between consumption in any two periods). The calculated risk aversion is 5.550 (2.925) for East Asia and 5.420 (1.680) for Japan/United States. The consumption share in the utility function parameterized by the definition equation of the time invariant welfare weight is 0.350 (0.275) for East Asia and 0.340 (0.340) for Japan/United States.[23] For comparison, in Backus et al. (1992, 1994), which focused on developed economies, the share parameter was 0.340. The subjective discount rate, β, is set equal to 0.990 (0.990) for both groups to replicate quarterly data as was in Backus et al. (1992, 1994). The calibrated key parameters for East Asia and Japan/United States in the two periods are shown in the Table 3.

Table 3
Calibration for the model, East Asia and Japan/United States, 1993-97 and 1999-2005

	East Asia		Japan/US		
Parameter	1993-97	1999-2005	1993-97	1999-2005	Remarks
σ_c	2.540	1.590	0.900	1.450	Elasticity of subst. between domestic tradable and imported consumption goods
σ_x	2.810	1.760	2.070	1.710	Elasticity of subst. between domestic and imported capital goods
σ_{cn}	0.404	0.370	0.230	0.104	Elasticity of subst. between domestic tradable and non-tradable consumption
γ	0.300	0.350	0.460	0.460	Capital distribution rate
δ	0.025	0.025	0.025	0.025	Rate of depreciation
η	0.500	0.600	0.600	0.950	Adjustment cost
$1-\mu\zeta$	5.550	2.925	5.420	1.680	Relative risk aversion
μ	0.350	0.275	0.340	0.340	Share of consumption in utility function
ω_c	0.175	0.191	0.199	0.254	Share of foreign consumption goods
ω_x	0.524	0.382	0.176	0.201	Share of foreign capital goods
ω_{cn}	0.390	0.445	0.749	0.767	Share of non-tradable consumption goods
β	0.990	0.990	0.990	0.990	Subjective discount rate

Sources: World Development Indicators, Penn World Table, CEIC databases, Asian International Input-Output Tables and author's calculations.

[22] Real interest rates are computed using the consumer price index as a deflator. The instrumental variables are lagged independent variables.

[23] See footnote 16.

Finally, the stochastic process is calibrated. As mentioned above, investment-specific technology can be derived as the price of final goods relative to that of capital goods, i.e., $z_t = p_t/q_t$. The relevant price data for each country can be obtained from the CEIC databases. The aggregated relative prices for the East Asian countries and for Japan/United States are constructed as the values for the countries in each group, where the weights are computed as the ratios of a country's 2000 real GDP to the total real GDP for the group.

In previous studies, the stochastic process for TFP was usually calibrated by applying the method developed in Backus et al. (1992, 1994). The logarithm of the Solow residual, s_t, can be estimated from output, y_t, employment, L_t, and the capital distribution rate, γ, using equation (21):

$$\ln(s_t) = \ln(y_t) - (1-\gamma)\ln(L_t) \tag{21}$$

As discussed in Backus et al. (1992), the absence of capital stock data for the calculation due to data constraints is not a serious problem. This is because the short-run volatility of capital stock is small and can be assumed to be orthogonal to the cycle. A more serious problem, however, is that for many countries, data on hours worked in all industries are not available. In the case of a specification without data on hours worked, as in equation (21), the Solow residual may include business cycle movements and cannot be regarded purely as representing technological change.

Therefore, the calculation procedure of Backus et al. (1992) is modified here. The output series is first filtered and the logarithm of employment multiplied by the labor distribution rate is then deducted from the logarithm of the filtered output. This is to prevent the residual from including business cycle movements.

The two measures of technology are converted to logarithmic values and then detrended using the HP filter.[24] Accordingly, the matrixes Γ_s and Σ_s for TFP are:

$$\Gamma_s = (\begin{matrix} \psi_{s_{11}} & \psi_{s_{12}} \\ \psi_{s_{21}} & \psi_{s_{22}} \end{matrix}) = \begin{pmatrix} 0.836 & -0.021 \\ -0.016 & 0.736 \end{pmatrix}, \begin{pmatrix} 0.847 & 0.099 \\ 0.060 & 0.796 \end{pmatrix} \tag{22}$$

$$\Sigma_s = 10^{-5} * \begin{pmatrix} 1.700 & 0.140 \\ 0.140 & 0.212 \end{pmatrix}, 10^{-6} * \begin{pmatrix} 1.800 & 0.300 \\ 0.300 & 3.590 \end{pmatrix} \tag{23}$$

The matrixes Γ_z and Σ_z for investment-specific technology are:

$$\Gamma_z = (\begin{matrix} \psi_{z_{11}} & \psi_{z_{12}} \\ \psi_{z_{21}} & \psi_{z_{22}} \end{matrix}) = \begin{pmatrix} 0.950 & 0.543 \\ -0.144 & 0.700 \end{pmatrix}, \begin{pmatrix} 0.853 & -0.050 \\ -0.119 & 0.798 \end{pmatrix} \tag{24}$$

$$\Sigma_z = 10^{-5} * \begin{pmatrix} 2.630 & 0.385 \\ 0.385 & 1.730 \end{pmatrix}, 10^{-5} * \begin{pmatrix} 9.070 & 1.230 \\ 1.230 & 2.700 \end{pmatrix} \tag{25}$$

Investment-specific technology had a relatively large cross-country feedback (from Japan/ United States to East Asia) of 0.543 in 1993-1997. Fig. 4 shows the movements of detrended investment-

[24]The method of aggregating countries' TFP is the same as that used with regard to investment-specific technology.

specific technology and TFP. In Fig. 4(a), we can see that the East Asian countries lagged behind the group of Japan and the United States in investment-specific technology in the first period.

(Insert Figure 4)

4 Simulation results

The results of the simulation are shown in Table 4(1), which presents the simulated correlations between East Asia and Japan/United States for output, consumption, and investment, as well as the volatility of both investment and the terms of trade for the two groups. The results were obtained using 1,000 replications over twenty-two quarters. The two kinds of volatility are computed as the standard deviations of these two variables (investment and terms of trade) and the investment volatility is divided by the standard deviation of output. The figures in square brackets are empirical results.[25]

First, regarding correlations with the corresponding foreign variables (output, investment and consumption), the model simulation successfully delivers factual results. It is especially noteworthy that the simulation solves the consumption-output anomaly discussed in the section 3.1.

As discussed in the previous section, the relative volatility of investment is the criterion by which the calibration of the adjustment cost parameter η is assessed. The simulation replicates the volatility of investment and the volatility of terms of trade well.

In the bottom of Table 4(1), the result of sensitivity analysis concerning the role of the depreciation rate in the model is presented. In the case of both $\delta_1 = \delta_2 = 0.5$ and $\delta_1 = \delta_2 = 1.0$, the correlations of output, investment and consumption increase from 1990s to 2000s. The extent of changes are different from the benchmark case ($\delta_1 = \delta_2 = 0.025$) but the direction of changes is the same.

Table 4(2) shows the results of other sensitivity analyses and allows us to pinpoint which aspects of the model are responsible for generating the benchmark simulation results. Several versions of the model are simulated with identical parameters to the benchmark case except for (i) the trade in capital goods between two areas, which is set to zero (w/o d_1, e_2); (ii) the trade in consumption goods, which is set to zero (w/o b_1, a_2); (iii) non-tradable consumption, which is set to zero (w/o cn_1, cn_2); (iv) investment-specific technology, which is set to zero (w/o z_1, z_2); (v) TFP, which is set to zero (w/o s_1, s_2). Furthermore, the bottom of Table 4(2) is the case in which the elasticities of substitution for 1999-2005 are used for both two periods (same elasticities).

These results lead us to conclude that the two mechanisms of the model, the trade in capital goods and investment-specific technology, are responsible for generating the benchmark results. Versions of the model without any of these two mechanisms cannot predict the increase of cross-correlation of output accompanied by the increase of cross-correlation of investment empirically observed as shown in Table 1(2) between East Asia and Japan/United States.

Compared to the traditional form of technology, TFP, investment specific technology is characterized as being embodied in traded capital goods and as strengthening the influence of the trade

[25]The empirical correlations are the same as in the Table 1(2).

Table 4(1)
Correlations of GDP, investment and consumption between, and the relative volatility of investment in, and the volatility of terms of trade in, East Asia and Japan/United States

	1993-97	1999-2005
GDP	-0.13	0.55
	[-0.12]	[0.43]
Investment	-0.49	0.39
	[-0.43]	[0.42]
Consumption	-0.22	0.11
	[-0.19]	[0.13]
Investment volatility		
East Asia	2.65	4.14
	[3.13]	[4.38]
Japan/US	5.57	5.07
	[4.87]	[4.61]
Terms of trade volatility	0.87	1.02
	[1.01]	[1.19]
$\delta_1 = \delta_2 = 0.5$		
GDP	0.23	0.57
Investment	-0.57	0.34
Consumption	0.07	0.15
$\delta_1 = \delta_2 = 1.0$		
GDP	0.42	0.54
Investment	0.32	0.44
Consumption	-0.79	-0.01

Source: Author's calculations.

Note: The figures in square brackets are empirical results which are calculated on a per capita basis except for the terms of trade.

Table 4(2)
Resultes of sensitivity analyses (Correlations of GDP, investment and consumption between East Asia and Japan/United States)

	1993-97			1999-2005		
	GDP	Investment	Consumption	GDP	Investment	Consumption
(1) benchmark	-0.13	-0.49	-0.22	0.55	0.39	0.11
(2) w/o d_1, e_2	-0.29	-0.19	-0.40	-0.28	-0.38	-0.36
(3) w/o b_1, a_2	-0.19	-0.45	-0.95	0.38	0.09	-0.49
(4) w/o cn_1, cn_2	-0.35	-0.98	0.95	0.64	-0.53	0.69
(5) w/o z_1, z_2	0.15	0.80	-0.85	0.79	0.68	0.64
(6) w/o s_1, s_2	-0.38	-0.90	0.19	0.66	0.24	0.05
(7) same elasticities	0.28	-0.39	-0.81	0.55	0.39	0.11

Source: Author's calculations.

Note: The elasticities of substitution for 1999-2005 are used for both periods in the case of (7).

in capital goods to economies involved in the model. As discussed earlier, international exchange of capital goods is likely to lead to international business cycle co-movements because capital goods are used for investment for both groups in the model. Investment is a form of demand which is usually important in determining business cycle fluctuations.

On the other hand, it is confirmed that the introduction of non-tradable consumption is effective to reduce the output-consumption anomaly. Model simulations without the non-tradable consumption result in cross-correlations of consumption which are larger than those of output.

The simulated correlations of some of the variables that are associated with investment are shown in Fig. 5. The changes observed in the second period can be summarized as follows: (i) The correlation between capital goods exports from Japan/United States to East Asia and vice versa jumped from -0.25 to 0.84, indicating that the trade in capital goods has been much more reciprocal recently; (ii) in each economic group, the co-movement between investment and capital goods exports has strengthened; and (iii) the correlation of capital goods exports from Asia to Japan/United States and investment in the latter has become stronger.

The reciprocal export of capital goods is a straightforward result of fragmentation. The closer link between East Asia's export of capital goods and investment in Japan/United States is consistent with the historical data analyzed in Section 2.3. The growth in East Asia's exports, as shown in Fig. 3, can be mainly attributed to the increase in capital goods exports, which in turn are used as investment. The stronger co-movement between investment and capital goods export in the second period is more significant on the part of the Japan/United States, and this seems to be due to the increased dependence on external demand in both countries in recent years.

(Insert Figure 5)

Fig. 6 (for 1993-1997) and Fig. 7 (for 1999-2005) plot the dynamic response of a number of home variables to positive home investment-specific technological changes and positive home TFP changes. Fig. 6(a) and Fig. 7(a) show the dynamic response to investment-specific technological changes in East Asia; Fig. 6(b) and Fig. 7(b) depict the dynamic response to investment-specific technological changes in Japan/United States; Fig. 6(c) and Fig. 7(c) present the response to TFP changes in East Asia; and Fig. 6(d) and Fig. 7(d) show the response to TFP changes in Japan/United States.

As can be seen in Fig. 6(a), the response of East Asia's net exports deteriorates substantially as its investment-specific technology changes. Given the lower technological level of East Asian countries compared to Japan/United States, the relative price of capital goods produced in East Asia increases largely due to the increasing demand for the goods despite the positive technological shock. Under the relatively large elasticity of substitution between domestic and imported capital goods in the East Asian countries in the earlier period, the increase in the relative price leads to a significant increase in East Asia's imports.

As pointed out in the previous section, investment-specific technology had a relatively large cross-country feedback (from Japan/United States to East Asia) of 0.543 in 1993-1997. As a result, the responses to investment-specific technological changes show relatively large fluctuations before they attenuate in East Asia and also in Japan/United States in this period.

(Insert Figures 6 and 7)

The above model simulation suggests that the main sources of business cycle synchronization between the developing countries of East Asia and the developed countries of Japan and the United States are the international exchange of capital goods and the spillover of technology embodied in imported capital goods accelerated by the expansion of production fragmentation.

5 Conclusion

The purpose of this paper was to analyze the factors responsible for co-movements of business cycles in the developing countries of East Asia and the major developed economies.

To this end, a DGE model was developed consisting of eight Asian countries on the one hand and Japan and the United States on the other. This approach was motivated by the fact that in earlier studies on the relationship between business cycles and trade focusing on the Asia-Pacific region, Frankel and Rose's (1998) approach or a regression analysis was more popular. While regression analyses provided many valuable insights, they provided no theoretical underpinning to explain how intra-industry trade induced by fragmentation leads to business cycle co-movements.

The model simulation for the two different periods revealed that the difference in the extent of business cycle synchronization between the two groups of countries in the 1990s and the 2000s can be attributed mainly to the expansion of fragmentation activities. The fragmentation of production was modeled as an exchange of capital goods among the countries concerned. Exports of capital goods have been becoming increasingly reciprocal, and with the stronger correlation between investment and capital goods exports for each of the groups, business cycles have become more synchronized recent years. Furthermore, the model includes investment-specific technology that is embodied in capital goods, and this plays the important role in replicating the international transmission of the business cycle.

In East Asia, some developing countries have become investors in other surrounding developing countries as well as recipients of investments from outside the area. It is expected that fragmentation, partly as a result of the expansion of production networks, will further gain momentum. Based on the simulation results presented here, we can expect that the business cycles of countries linked through such networks will become more synchronized and that this will have a great impact on Asian economic integration.

The main purpose of the current study is to document and explain business cycle synchronization in terms of real variables. The synchronization in nominal variables such as inflation, interest rates and exchange rates, is a topic for future research. For example, Wang and Wen (2007) documented that the average cross-country correlation of inflation is significantly and systematically stronger than that of output, while the cross-country correlation of money growth is essentially zero. Along with such nominal phenomena, it is becoming increasingly important to analyze the role of financial factors in business cycle fluctuations even for developing economies, including those in Asia.

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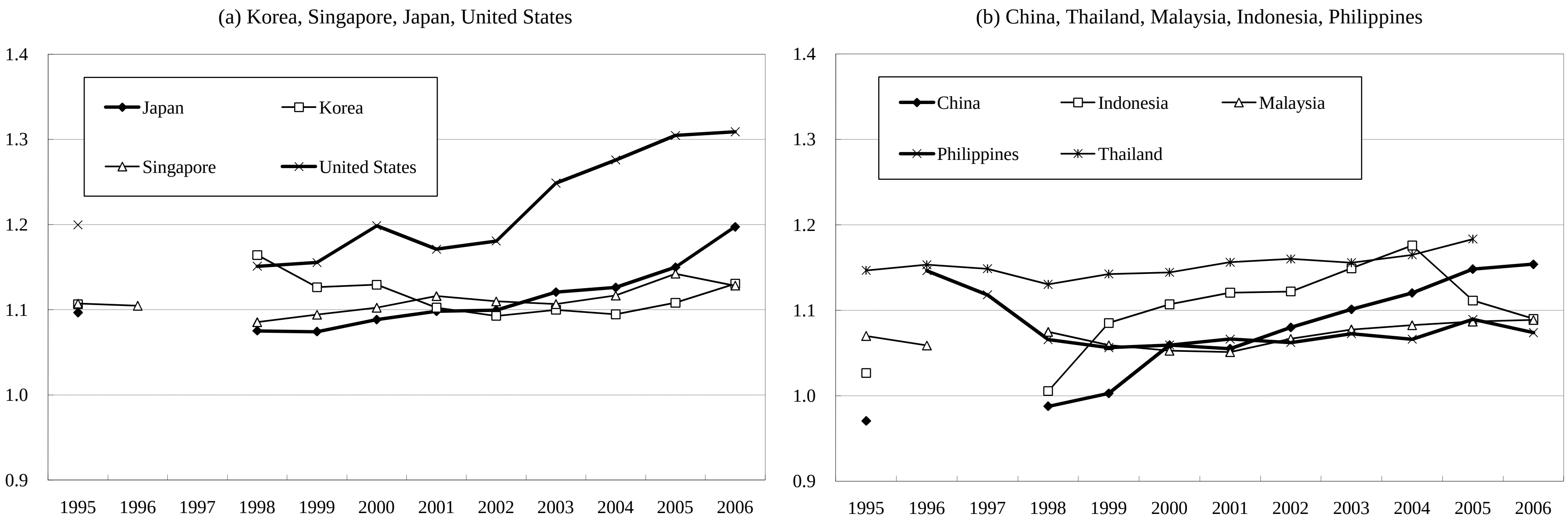


Fig. 1. Intensity of trade in capital goods (including intermediate goods). *Note* : Unreported years are due to missing values in the datasource.
Source : UN Comtrade database.

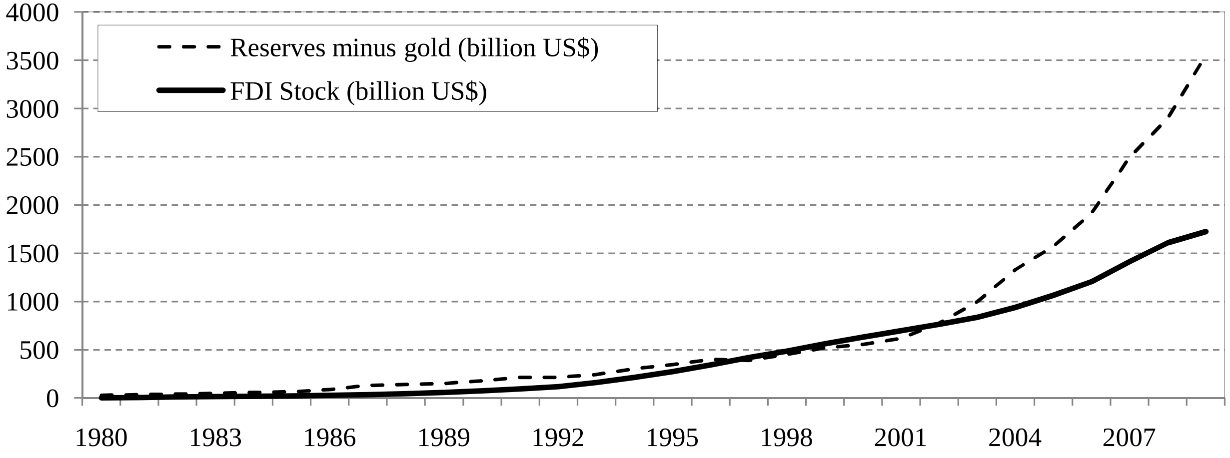


Fig. 2. Total reserves minus gold and FDI stock in East Asian eight countries. *Note* : The FDI stock in each year is the cumulated value for years since 1980.
Source : International Financial Statistics.

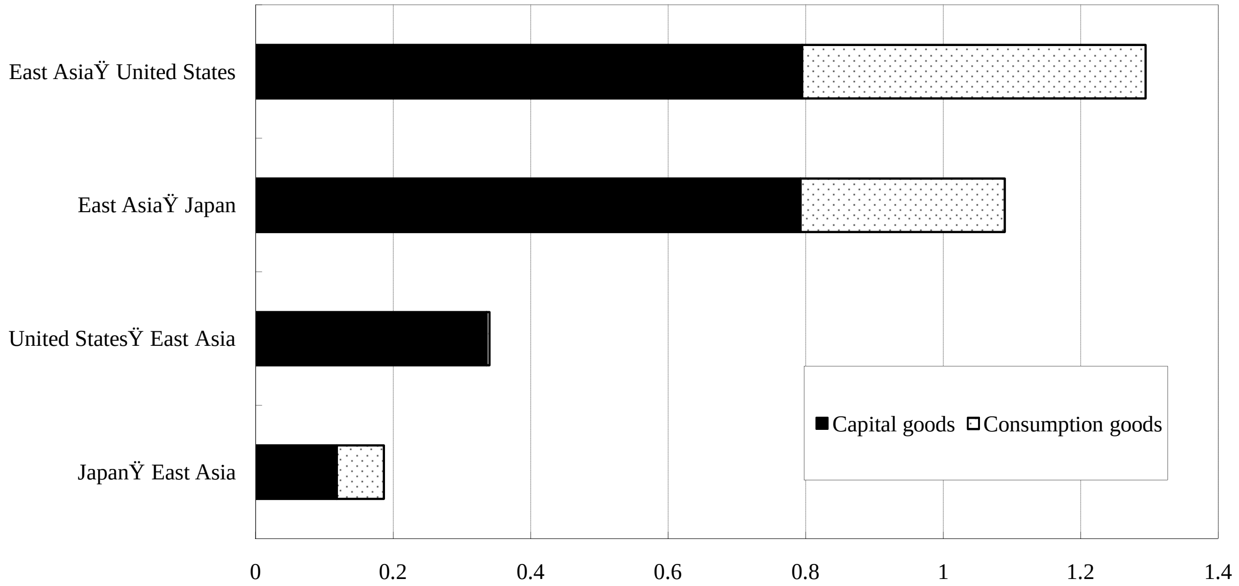
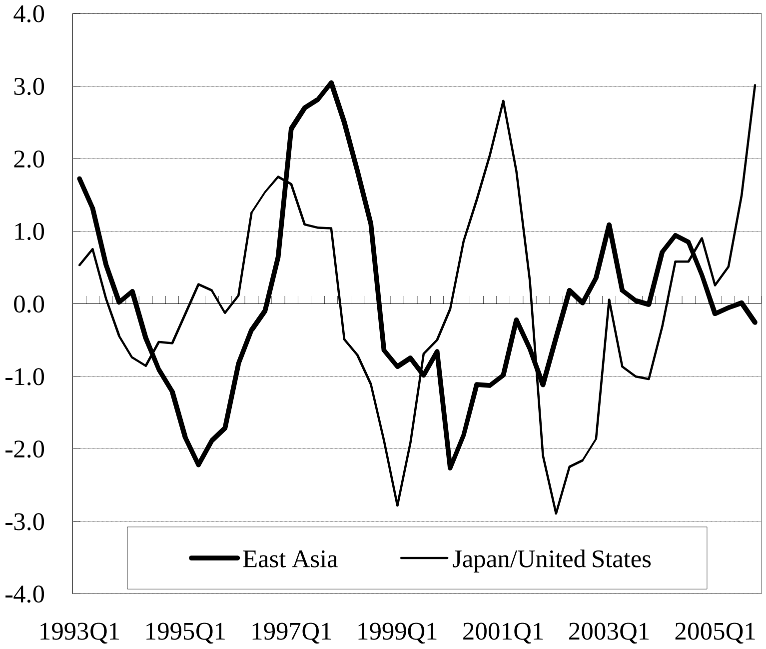


Fig. 3. Contribution of capital and consumption goods to total export growth from 1995 to 2005. *Note* : Capital goods include intermediate goods. The total export growth rate is the ratio of the difference between 1995 and 2005 export volumes to export volume in 1995. Nominal export values (US$) used to calculate the growth rates are from UN Comtrade database. Deflators for each goods are from the United States Department of Labor, Bureau of Labor Statistics.

Source : UN Comtrade database and the United States Department of Labor, Bureau of Labor Statistics.

(a) Investment-specific technology



(b) TFP

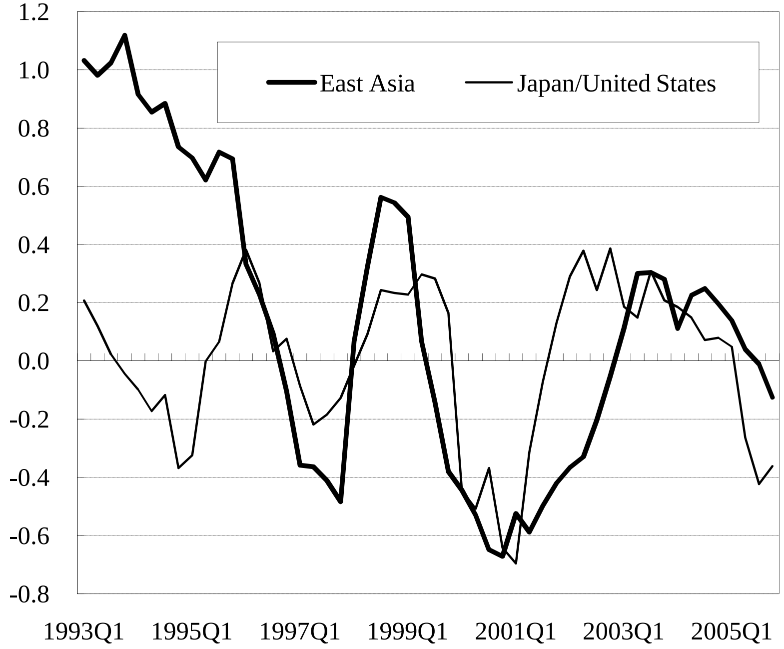


Fig. 4. Detrended movement of technology in East Asia and Japan/United States. *Note* : The vertical axis indicates the deviation from the steady state (in %).
Source : Author's calculations.

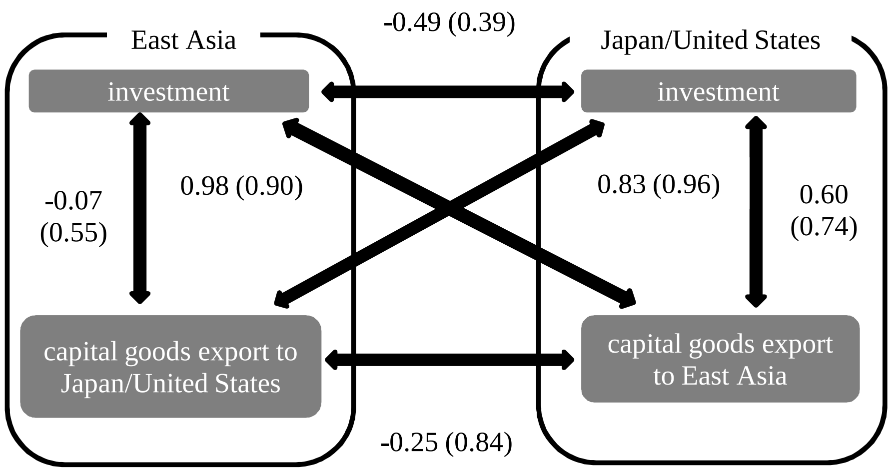


Fig. 5. Simulated correlations between investments and exports of capital goods. *Notes*: Figures without parentheses are for 1993-1997, and figures in parentheses are for 1999-2005.
Source: Author's calculations.

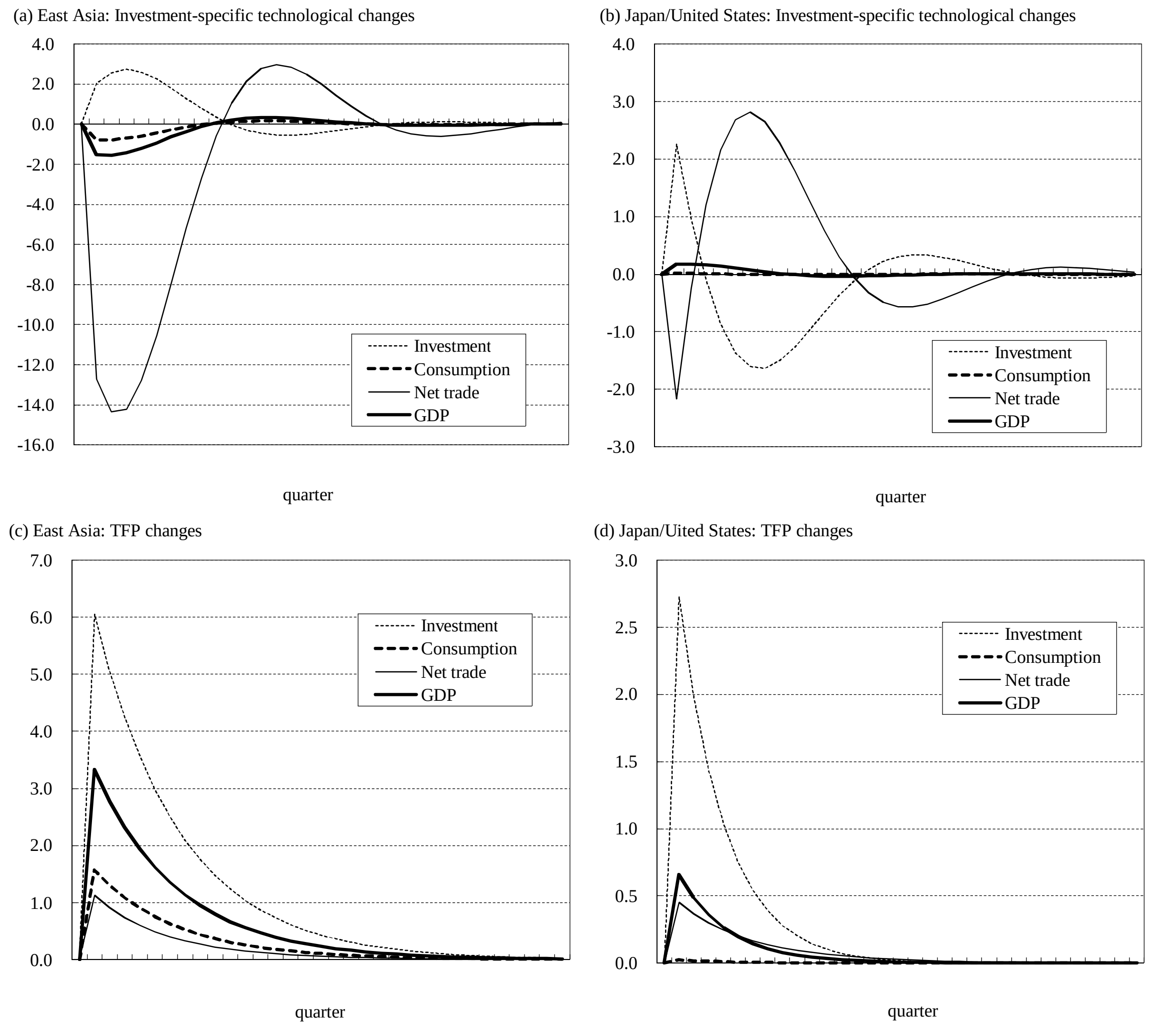


Fig. 6. Dynamic responses to a positive domestic productivity shock (1993−1997). *Note*: The vertical axis indicates the deviation from the steady state (in %).
Source: Author's calculations.

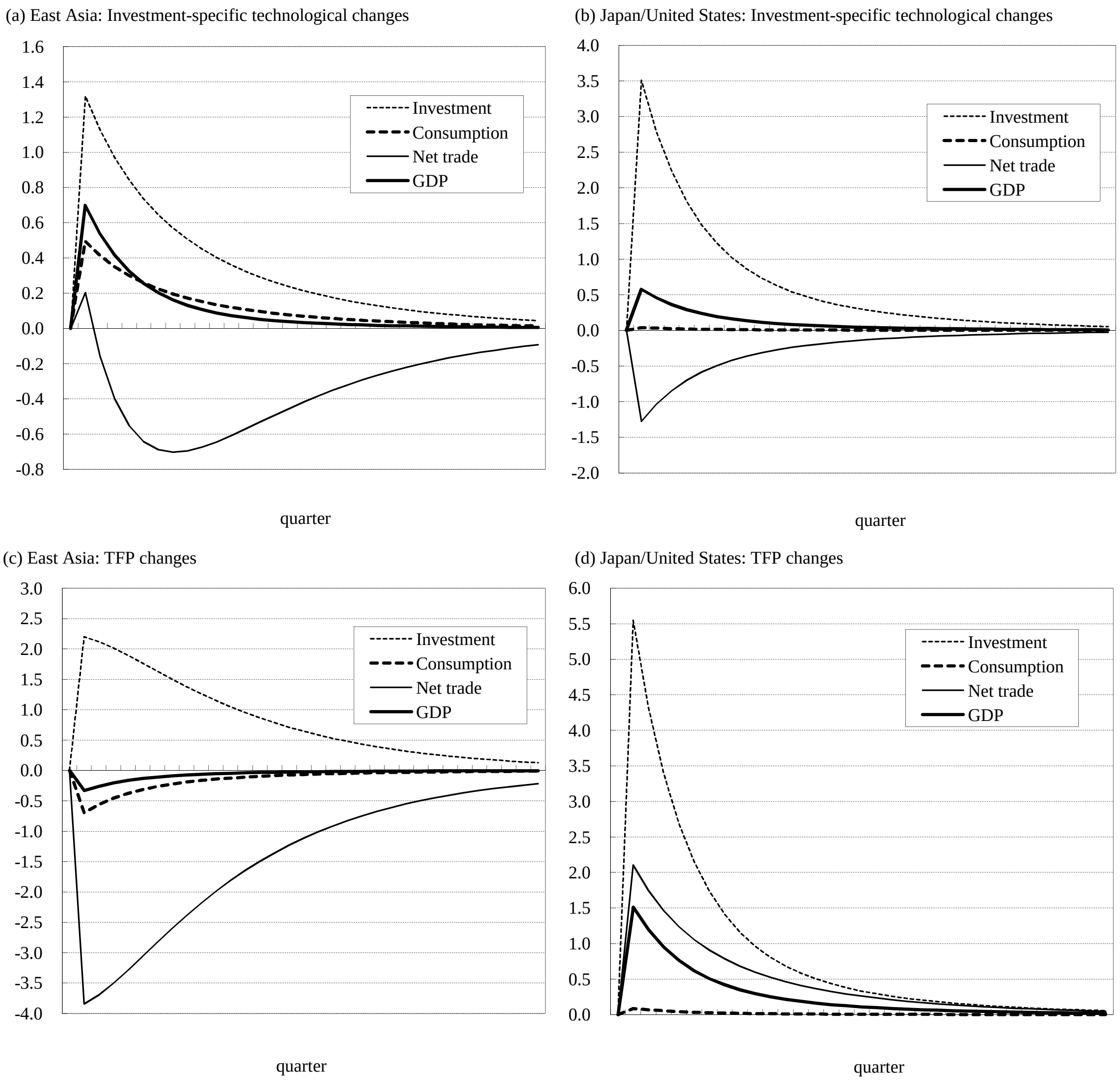


Fig. 7. Dynamic responses to a positive domestic productivity shock（1999－2005）. *Note* : The vertical axis indicates the deviation from the steady state (in %).
Source : Author's calculations.