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in an International Business
Cycle Model Matter?

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Does the Number of Countries in an International Business Cycle Model Matter?

Myunghyun Kim*

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Does the Number of Countries in an International Business Cycle Model Matter?

Until the 1990s, standard models with two large open economies (i.e. the U.S. and Europe) provided plausible representations of the world economy. However, with the emergence of many countries such as China since then, this approach no longer seems reasonable. In line with this change to the global economic environment, there also have been changes in cross-country correlations: the output correlation between the U.S. and Europe has risen, and their consumption correlation has slightly fallen. Accordingly, this paper adds many countries to a standard model to show that doing so can capture the transition in the cross-country correlations. By analytical investigation, I first show that as the number of countries in a simple model increases, the output correlation rises and the consumption correlation falls. A quantitative analysis with a more general model also shows that when the model has more countries, it yields a higher output correlation and a smaller consumption correlation.

Keywords: International business cycles, Number of countries, n-country model, Output correlation, Consumption correlation

JEL Classification: F40, F41, F44

I . Introduction

Until the 1990s, modeling the world economy with two large open economies (i.e. the U.S and Europe) as in standard international business cycle models seemed to be reasonable and plausible, since their weight in the world economy was substantial.¹⁾ Typical international business cycle models with two large open economies, however, seem to be no longer appropriate, as many developing countries such as Brazil, China, India, and Russia have emerged as global players since the 1990s. As a consequence, it has become an almost impossible mission to explain international business cycles with two-country models. Surprisingly, nevertheless, most international business cycle models are still sticking to two symmetric countries in their models (or three countries, on rare occasion). This paper constructs two international business cycle models with many countries to consider this change in the global economic environment. Both the analytical investigation with a simple model and the quantitative analysis with a more general model show that adding many countries to the models helps to explain key international business cycle statistics. Specifically, doing so increases the cross- country output correlation and decreases the cross-country consumption correlation in the models.

Explaining international business cycle comovements, in particular cross-country output and consumption correlations, is one of the central topics in international macroeconomics. The first paper on this is Backus, Kehoe and Kydland (1992, BKK). BKK construct a symmetric two-country real business cycle model with a single consumption good and complete markets, and show that their model generates a negative output correlation between the two countries and

1) During the 1960s the combined weight of the U.S. and E.U. in the world economy was around 67% in terms of GDP, according to World Bank data. Since the 1990s, however, their combined weight has continuously decreased, and during the period 2010-2017 it was about 45%.

a very high cross-country consumption correlation close to 1. However, from the data the cross-country output correlation is positive and higher than the cross-country consumption correlation, which is also positive. These discrepancies between the data and standard models' predictions are called the “quantity anomaly.”²⁾ Motivated by the seminal work of BKK, many papers have tried to tackle this puzzle. For example, Baxter and Crucini (1995, BC) assume incomplete markets and highly persistent productivity shocks (i.e. unit-root productivity shocks) that do not spill over from one country to the other.³⁾ Some papers have tried to explain the merely high cross-country output correlation (i.e. business cycle synchronization) in the data.⁴⁾ All these papers, however, have had only limited success in explaining international business cycle comovements. Specifically, even in papers that successfully eliminated the quantity anomaly, the cross-country output correlation was too low compared to the data or the cross-country consumption correlation was negative. Meanwhile, in papers that succeeded in generating high output correlation, the quantity anomaly survived. Regardless of their success or failure, all these studies consider only two countries in their models. This paper tries to address this shortcoming in the literature by considering many countries in a standard international business cycle model.

2) Alternatively, the “international consumption correlation puzzle” or the “BKK puzzle.”

3) In addition, Stockman and Tesar (1995) introduce non-traded goods and taste shocks, Ravn (1997) assumes a more general technology shock process, Kehoe and Perri (2002) add informational frictions, Corsetti, Dedola and Leduc (2008) consider the distributional sector, Dmitriev and Roberts (2012) consider Greenwood-Hercowitz-Huffman (GHH) preferences and internal habit formation in consumption, Oviedo and Singh (2013) introduce investment composition, Kim (2018) considers commodity trade structures, and so on.

4) For example, Faia (2007) uses financial frictions, Ueda (2012) introduces cross-border lendings and borrowings, and Kollmann (2017) considers recursive intertemporal preferences.

Table 1. Correlations with the U.S.

	Output correlation		Consumption correlation	
	Q1 1970–Q4 1989	Q1 1990–Q3 2018	Q1 1970–Q4 1989	Q1 1990–Q3 2018
Belgium	0.33	0.58	0.19	0.11
Canada	0.74	0.77	0.52	0.56
Denmark	0.64	0.68	0.54	0.47
France	0.43	0.62	0.36	0.43
Germany	0.61	0.38	0.55	0.13
Italy	0.40	0.48	−0.04	0.28
Japan	0.59	0.49	0.48	0.02
Netherlands	0.49	0.45	0.51	0.20
Spain	0.30	0.27	0.22	0.41
Switzerland	0.42	0.61	0.42	0.12
U.K.	0.67	0.77	0.45	0.66
Europe	0.47	0.52	0.35	0.33

Notes: Statistics are based on detrended data using the Hodrick-Prescott filter. All series are in logarithms. The statistics for Europe are the GDP-weighted averages of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, Turkey and the U.K. The GDP-weights are computed using nominal GDP denominated in U.S. dollars from the IMF World Economic Outlook. The source of output and consumption is the OECD Quarterly National Account.

Due to the rapid changes in the global economic environment since the 1990s, international business cycles may have changed as well. The output and consumption correlations between the U.S. and major countries during the pre-1990 and the post-1990 periods are shown in Table 1. Although the directions of changes in the correlations slightly differ among countries, the output correlations have generally increased and the consumption correlations have roughly decreased in the post-1990 period compared to the pre-1990 period. In particular, the output correlation between the U.S. and Europe (I focus on the correlations between the U.S. and Europe, as do most studies including BKK) has risen from 0.47 to 0.52, and the consumption correlation between them has slightly decreased from 0.35 to 0.33.⁵⁾

5) The reason why the changes in the correlations are not very large may stem from the fact that China, the largest country among those who have emerged since the 1990s, is maintaining capital controls, and international capital movements are important in the changes, as we will see later.

These changes in international business cycles since 1990 may result from the fact that during the pre-1990 period the world economy was able to be approximately represented by two large open economies (the U.S. and Europe), but during the post-1990 period representing the world economy with the two countries has become difficult as many countries have emerged as global players. Therefore, the number of countries in international business cycle models may matter, and we hence may need to consider models with many countries, rather than typical models only with two countries, to capture these changes in international business cycles in the data.

To explain, in the standard symmetric two-country model with a single consumption good and complete markets, such as that in BKK, a positive productivity shock to a country (say A) leads to an increase in its output. Since A becomes more productive due to the shock, resources (i.e. capital that is mobile across countries) in the other country (say B) are shifted to A , causing a fall in B 's output. Hence, in the two-country economy, the outputs of A and B are negatively correlated. However, suppose that the model includes three countries (say A , B and C). A positive productivity shock to A will make A become more productive than B and C , and thus A will draw capital from B and C . Nonetheless, since A has one more country (i.e. C) to draw resources than in the two-country model, the capital of B and C will fall by less than in the two-country case. Consequently, in response to the positive productivity shock to A , the output of B and C will go down by less compared to the two-country model, which will enable the cross-country output correlation to be higher. In short, it would be expected that the higher the number of countries in an international business cycle model, the higher the cross-country output correlation.

As for the cross-country consumption correlation, in the standard two-country model with complete markets (BKK's model), when a positive productivity shock hits A , its households increase their consumption by some, but not all, of the rise in its output. This is

because under complete markets households want to smooth consumption by sharing some of the increased output with B in exchange for the same share when a positive productivity shock hits B . Hence, consumption in B goes up, which causes a very high cross-country consumption correlation. In the three-country case, however, A has one more country (i.e. C) to share its increased output than in the two-country case. Therefore, A will share a smaller amount of its increased output with each country to smooth consumption. Accordingly, the consumption of B and C will increase by less than in the two-country model, which will bring about a lower cross-country consumption correlation. Alternatively, if there are many countries, the weight of A in the world economy will fall, meaning that positive productivity shocks to A will bring about a smaller fall in the world price of the consumption good. The smaller decrease in the world price will lead to a smaller increase in real wages (the relative price of leisure to the price of the consumption good) in B and C , if other factors are constant, which will enable consumption in B and C to go up by less compared to those in the two-country case. Hence, the cross-country consumption correlation will become lower.

The main goal of this paper is to show that in line with the changes in the global economic environment and international business cycles in the data since the 1990s, the higher the number of countries in an international business cycle model, the higher the output correlation and the lower the consumption correlation the model produces, and thus the quantity anomaly is also mitigated to some degree. To do so, I first conduct an analytical investigation with a simple n -country model. I then carry out a quantitative analysis by using a more general n -country model. For the quantitative analysis, I consider both complete and incomplete asset markets, and both trend stationary and unit-root productivity shocks. Consistent with the expectation, both the analytical and quantitative studies, indeed, show that as the number of countries in the two models increases, the

cross-country output correlation goes up and the cross-country consumption correlation falls.

The remainder of the paper is organized as follows. With a simple n -country model, Section II analytically shows that as the number of countries in the model increases, the cross-country output correlation increases but the cross-country consumption correlation falls. Section III provides a more general n -country model by extending the model of BC for a quantitative analysis, and shows that the simulation results of the model are consistent with the analytical results in Section II. The simulation results for various asset market structures and productivity shock processes are also presented in Section III. Section IV concludes.

II. Analytical Investigation Using a Simple Model

In this section, I analytically investigate whether a simple n -country model with more countries generates a higher cross-country output correlation and a lower cross-country consumption correlation. To explore the economic mechanism for the differential cross-country correlations depending on the number of countries in the model, I then study the impulse responses of several variables in the model. Specifically, I show that as the number of countries in the model increases, the output of country j decreases by less in response to a positive productivity shock to country i , $i \neq j$, whilst the consumption of country j increases by less in response to the same shock.

1. The simple model

The simple model is based on the models of BKK and BC. For simplicity, I assume that capital is fixed.⁶⁾ Therefore, it should be

6) Since omitting capital and investment substantially simplifies the analysis, this assumption is frequently used in many analytical studies.

noted that there are some discrepancies between the explanations in this section and the previous. Other features of the model are the same as those of BKK and BC. Specifically, the world economy consists of $n \geq 2$ countries, there exists a single consumption good, and asset markets are complete, which means that individuals in the model are free to trade any state-contingent asset they wish. I assume symmetry across countries as usual in the standard international business cycle literature. Hence, the impulse responses of all variables in all countries, with the exception of country i , to a productivity shock to country i and the cross-country correlations for all variables for all country pairs are equal.

Equilibrium of the simple n -country model can be found by carrying out a standard Lagrangian problem, as specified below:

$$\begin{aligned} \max_{C_t^i, L_t^i, N_t^i, W_t^i, P_t} \mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta^t & \left[\sum_{i=1}^n \frac{1}{n} U^i(C_t^i, L_t^i) + \sum_{i=1}^n \frac{1}{n} W_t^i (1 - L_t^i - N_t^i) \right. \\ & \left. + P_t \sum_{i=1}^n \frac{1}{n} (A_t^i N_t^{i^{1-\alpha}} - C_t^i) \right], \end{aligned} \quad (1)$$

where superscript $i = 1, 2, \dots, n$ denotes countries and $U^i(C_t^i, L_t^i) = \frac{(C_t^{i\mu} L_t^{i^{1-\mu}})^\gamma}{\gamma}$. E is the expectations operator, C_t^i is consumption, L_t^i is leisure, N_t^i is time allocated to work, and A_t^i is total factor productivity. W_t^i and P_t are Lagrangian multipliers. These multipliers have natural interpretations: W_t^i is the wage rate and P_t is the price of the consumption good. Finally, the real wage rate, an additional variable of our interest, can be defined by W_t^i/P_t .

Productivity follows an AR(1) process as usual:

$$A_t = \Omega A_{t-1} + \mathbf{e}_t, \quad (2)$$

where $A_t = [\ln A_t^1, \ln A_t^2, \dots, \ln A_t^n]'$ and Ω is an $n \times n$ matrix of coefficients.

$\mathbf{e}_t = [e_t^1, e_t^2, \dots, e_t^n]'$ is the innovation to $\mathcal{A}_t$. For simplicity of the model, I further assume that the off-diagonal elements of Ω are all zero, i.e. shocks do not have international spillovers, and that all diagonal elements of Ω have the same value of $\varrho \in (0, 1]$. The correlations between shocks ρ_A are the same for all country pairs and $\rho_A > 0$.

The first-order conditions for this Lagrangian problem are

$$P_t = \mu C_t^{\mu\gamma-1} L_t^{i^{\gamma(1-\mu)}}, \quad (3)$$

$$W_t^i = (1-\mu) C_t^{\mu\gamma} L_t^{i^{\gamma(1-\mu)-1}}, \quad (4)$$

$$W_t^i = (1-\alpha) P_t A_t^i N_t^{i^{-\alpha}}, \quad (5)$$

$$0 = 1 - L_t^i - N_t^i, \quad (6)$$

$$\sum_{i=1}^n A_t^i N_t^{i^{1-\alpha}} = \sum_{i=1}^n C_t^i. \quad (7)$$

These first-order conditions can be combined to obtain:

$$C_t^{\mu\gamma-1} L_t^{i^{\gamma(1-\mu)}} = C_t^{\mu\gamma-1} L_t^{j^{\gamma(1-\mu)}}, \quad j \neq i, \quad (8)$$

$$(1-\mu) C_t^i = (1-\alpha) \mu L_t^i A_t^i N_t^{i^{-\alpha}}, \quad (9)$$

$$\sum_{i=1}^n Y_t^i = \sum_{i=1}^n A_t^i N_t^{i^{1-\alpha}} = \sum_{i=1}^n C_t^i. \quad (10)$$

The corresponding log-linearized forms of equations (8)-(10) are

$$\chi \hat{C}_t^j - \xi \hat{N}_t^j = \chi \hat{C}_t^i - \xi \hat{N}_t^i, \quad j \neq i, \quad (11)$$

$$\hat{C}_t^j = \hat{A}_t^j - \varphi \hat{N}_t^j, \quad (12)$$

$$\sum_{i=1}^n \hat{Y}_t^i = \sum_{i=1}^n \left\{ \hat{A}_t^i + (1-\alpha) \hat{N}_t^i \right\} = \sum_{i=1}^n \hat{C}_t^i, \quad (13)$$

with $\chi = \mu\gamma - 1$, $\xi = \frac{N\gamma(1-\mu)}{1-N}$ and $\varphi = \alpha + \frac{N}{1-N}$. The hatted variables denote the log-deviations of the variables from their steady state values, and the variables without time subscript t refer to their steady state values. Due to the symmetry, each variable has the same steady state value across countries, i.e. $W_t^i = W$, $Y_t^i = Y$, $C_t^i = C$ and $N_t^i = N$ for all i .

Finally, the equations for the real wage and its log-linearized form can be written as:

$$w_t^i = \frac{W_t^i}{P_t} = \frac{1-\mu}{\mu} \frac{C_t^i}{1-N_t^i} = (1-\alpha)A_t^i N_t^{i-\alpha}, \quad (14)$$

$$\hat{w}_t^i = \hat{W}_t^i - \hat{P}_t = \hat{C}_t^i + \frac{N}{1-N} \hat{N}_t^i = \hat{A}_t^i - \alpha \hat{N}_t^i. \quad (15)$$

2. Solution of the model

I solve the system of the above linear equations by applying the method of undetermined coefficients. The policy rules for the jump variables in the model are⁷⁾

$$C_t^i = C + C \left\{ (1 - \kappa\varphi) \hat{A}_t^i + \frac{\kappa\varphi}{n} \sum_{l=1}^n \hat{A}_t^l \right\}, \quad (16)$$

$$N_t^i = N + N \left\{ \kappa \hat{A}_t^i - \frac{\kappa}{n} \sum_{l=1}^n \hat{A}_t^l \right\}, \quad (17)$$

with $\kappa = \frac{\chi}{\xi + \chi\varphi}$. Since $\hat{Y}_t^i = \hat{A}_t^i + (1-\alpha)\hat{N}_t^i$, $\hat{Y}_t^i = (1 + (1-\alpha)\kappa)\hat{A}_t^i - (1-\alpha)$

$\frac{\kappa}{n} \sum_{l=1}^n \hat{A}_t^l$. By using $\hat{Y}_t^i = \frac{Y_t^i - Y}{Y}$, Y_t^i can be written as

7) See Appendix A for details.

$$Y_t^i = Y + Y \left\{ (1 + (1 - \alpha)\kappa) \hat{A}_t^i - (1 - \alpha) \frac{\kappa}{n} \sum_{l=1}^n \hat{A}_t^l \right\}. \quad (18)$$

Since capital is fixed in this simple model, the price of the consumption good and the real wage are important in understanding output and consumption fluctuations. We thus need to obtain policy rules for those variables. Substituting equations (16) and (17) into equations (3) and (15) gives the policy rules for the two additional variables of interest (P_t and w_t^i):

$$P_t = P + P \left\{ (\chi - \kappa(\chi\varphi - \xi)) \hat{A}_t^i + \frac{\kappa(\chi\varphi - \xi)}{n} \sum_{l=1}^n \hat{A}_t^l \right\}, \quad (19)$$

$$w_t^i = w + w \left\{ \left(1 - \kappa\varphi + \frac{N}{1-N} \kappa \right) \hat{A}_t^i - \frac{\kappa}{n} \left(\varphi - \frac{N}{1-N} \right) \sum_{l=1}^n \hat{A}_t^l \right\}. \quad (20)$$

3. Cross-country correlations

Before obtaining the functional forms of the cross-country consumption and output correlations in the model, we need to find the functional forms of variances of those variables, since the functional forms of the correlations contain the variances.

σ_C^2 , σ_Y^2 and σ_A^2 denote the variances of consumption, output and productivity, respectively. Note that due to the symmetry, they are equal for all i . Taking the variances of equations (16) and (18) and using $cov(A_t^i, A_t^j) = \rho_A \sigma_A^2$ for all i and j ($i \neq j$) give the expressions of σ_C^2 and σ_Y^2 :

$$\begin{aligned} \sigma_C^2 = C^2 \sigma_A^2 & \left[\left(1 - \frac{(n-1)\kappa\varphi}{n} \right)^2 + (n-1) \left(\frac{\kappa\varphi}{n} \right)^2 + \right. \\ & \left. 2(n-1) \left(1 - \frac{(n-1)\kappa\varphi}{n} \right) \frac{\kappa\varphi}{n} \rho_A + (n-1)(n-2) \left(\frac{\kappa\varphi}{n} \right)^2 \rho_A \right], \end{aligned} \quad (21)$$

$$\sigma_Y^2 = Y^2 \sigma_A^2 \left[\left(1 + (1-\alpha) \frac{(n-1)\kappa}{n} \right)^2 + (n-1)(1-\alpha)^2 \left(\frac{\kappa}{n} \right)^2 - 2(n-1) \times \right. \\ \left. (1-\alpha) \left(1 + (1-\alpha) \frac{(n-1)\kappa}{n} \right) \frac{\kappa}{n} \rho_A + (n-1)(n-2)(1-\alpha)^2 \left(\frac{\kappa}{n} \right)^2 \rho_A \right]. \quad (22)$$

As for the cross-country consumption correlation, we can obtain the functional form of it by using equation (16). Denote $\rho_{C^i, C^j} = \rho_C$ for all i and j ($i \neq j$) the cross-country correlation of consumption. To find out the functional form of ρ_C , we first obtain $C_t^i + C_t^j$ from equation (16), and then take the variance of $C_t^i + C_t^j$. By using the definition of correlation, $\rho_C = \frac{\text{cov}(C_t^i, C_t^j)}{\sigma_{C^i} \sigma_{C^j}} = \frac{\text{cov}(C_t^i, C_t^j)}{\sigma_C^2}$ and $\text{cov}(C_t^i, C_t^j) = \rho_C \sigma_C^2$,

$$\rho_C = \frac{C^2 \sigma_A^2}{2\sigma_C^2} f(n) - 1, \quad (23)$$

where $f(n) = 2(1 + \rho_A) \left(1 - \frac{(n-2)\kappa\varphi}{n} \right)^2 + (n-2) \left(\frac{2\kappa\varphi}{n} \right)^2 (1 + (n-3)\rho_A) + 4(n-2) \left(1 - \frac{(n-2)\kappa\varphi}{n} \right) \frac{2\kappa\varphi}{n} \rho_A$.

Proposition 1. *Under any reasonable parameterization, as the number of countries n grows in the model, the cross-country consumption correlation ρ_C falls.*

Differentiating equation (23) with respect to n gives

$$\frac{\partial \rho_C}{\partial n} = \frac{\kappa\varphi(\kappa\varphi-2)(\kappa\varphi-1)^2(\rho_A-1)^2}{[n\{\kappa\varphi(\kappa\varphi-2)(\rho_A-1)-1\}-\kappa\varphi(\kappa\varphi-2)(\rho_A-1)]^2}. \quad (24)$$

Under the standard parameterization, $\mu = 0.34$, $\gamma = -1$, $\alpha = 0.36$, $\rho_A = 0.258$ and $\varphi = 0.906$, which are the same parameter values used in

BKK. Accordingly, $N = 0.2479$, $\varphi = 0.6897$, $\chi = -1.34$, $\xi = -0.2176$ and $\kappa = 1.1736$. Since $\kappa\varphi(\kappa\varphi - 2) < 0$, $\frac{\partial \rho_C}{\partial n} < 0$. That is, the more countries the model has, the lower the cross-country consumption correlation it generates.

With regard to the cross-country correlation of output ($\rho_{Y^i, Y^j} = \rho_Y$ for all i and j , $i \neq j$), obtaining $Y_t^i + Y_t^j$ from equation (18), taking the variance of $Y_t^i + Y_t^j$ and using the definition of correlation ($\rho_Y = \frac{\text{cov}(Y_t^i, Y_t^j)}{\sigma_{Y^i}\sigma_{Y^j}} = \frac{\text{cov}(Y_t^i, Y_t^j)}{\sigma_Y^2}$ and $\text{cov}(Y_t^i, Y_t^j) = \rho_Y \sigma_Y^2$) give the explicit expression of ρ_Y :

$$\rho_Y = \frac{Y^2 \sigma_A^2}{2\sigma_Y^2} g(n) - 1, \quad (25)$$

where $g(n) = 2(1 + \rho_A) \left(1 + (1 - \alpha) \frac{(n-2)\kappa}{n} \right)^2 + (n-2)(1 - \alpha)^2 \left(\frac{2\kappa}{n} \right)^2 (1 + (n-3)\rho_A) - 4(n-2)(1 - \alpha) \left(1 + (1 - \alpha) \frac{(n-2)\kappa}{n} \right) \frac{2\kappa}{n} \rho_A$.

Proposition 2. *Under the standard parameterization, the cross-country output correlation ρ_Y goes up as the number of countries n increases.*

We can obtain the derivative of ρ_Y with respect to n by using equation (25).

$$\begin{aligned} \frac{\partial \rho_Y}{\partial n} = & \left[\kappa(\alpha - 1)(\kappa(\alpha - 1) - 2)(\kappa(\alpha - 1) - 1)^2(\rho_A - 1)^2 \right] \left[n\{\kappa(\alpha - 1) \times \right. \\ & \left. (\kappa(\alpha - 1) - 2)(\rho_A - 1) - 1\} - \kappa(\alpha - 1)(\kappa(\alpha - 1) - 2)(\rho_A - 1) \right]^{-2}. \end{aligned} \quad (26)$$

Since under the standard parameterization $\kappa(\alpha - 1)(\kappa(\alpha - 1) - 2) > 0$, $\frac{\partial \rho_Y}{\partial n} > 0$. Hence, when there exist more countries in the model, its

cross-country output correlation is higher.

To sum up, in this section, it is analytically shown that if there are many countries in a simple n -country international business cycle model, the cross-country correlation of consumption becomes lower, whilst the cross-country correlation of output becomes higher compared to the case in which only two countries exist as in the standard models. These analytical results clearly show that international business cycle models should include many countries in order to properly explain international business cycles after the 1990s.

4. Impulse responses

In this section, I study the impulse responses of the model to understand how it can generate lower cross-country consumption correlation and higher cross-country output correlation as the number of countries in the model n grows. The impulse response of a variable z_{t+h}^i , $h \geq 0$ in period $t+h$ to a productivity shock to country j in period t e_t^j is defined by $\frac{\partial z_{t+h}^i}{\partial e_t^j}$. It can be obtained by using the policy rules and the first-order conditions in the previous section.

Proposition 3. *Under any reasonable parameterization, in response to a positive productivity shock to country j , the price of the consumption good P_t falls by less as the number of countries n increases.*

Differentiating equation (19) with respect to e_t^j and using $\frac{\partial \hat{A}_t^i}{\partial e_t^j} = \frac{\partial e_t^i}{\partial e_t^j} = \rho_A$ and $\frac{\partial \hat{A}_t^j}{\partial e_t^j} = \frac{\partial e_t^j}{\partial e_t^j} = 1$ for all i and j ($i \neq j$), which can be obtained from equation (2), yield the impulse response of P_{t+h} to e_t^j :

$$\frac{\partial P_{t+h}}{\partial e_t^j} = P_0^h \left\{ \chi \rho_A + \frac{\kappa(\chi\varphi - \xi)(1 - \rho_A)}{n} \right\}. \quad (27)$$

Both $\chi\rho_A$ and $\kappa(\chi\varphi - \xi)(1 - \rho_A)/n$ are negative under the standard parameterization. Hence, $\frac{\partial P_{t+h}}{\partial e_t^j} < 0$. That is, since a positive productivity shock to country j leads to an increase in its production of the consumption good, the price of the consumption good falls. Furthermore, because $\kappa(\chi\varphi - \xi)(1 - \rho_A)$ is negative, $\frac{\partial}{\partial n} \left(\frac{\partial P_{t+h}}{\partial e_t^j} \right) = -PQ^h \kappa(\chi\varphi - \xi)(1 - \rho_A)/n^2 > 0$, which means that when there are more countries in the model, the price goes down by less in response to a positive productivity shock to country j . Recall that the more countries in the model, the less weight of an individual country in the world economy. Therefore, when more countries exist in the model, the effect of positive productivity shocks to a certain country on the price becomes weaker.

Proposition 4. *Under the standard parameterization, if the model has more countries, a positive productivity shock to country j leads to a smaller increase in the real wage in country i w_t^i .*

By differentiating equation (20) with respect to e_t^j , we can obtain the impulse response of w_t^i to e_t^j :

$$\frac{\partial w_{t+h}^i}{\partial e_t^j} = wQ^h \left\{ \rho_A + \frac{\kappa(1 - \rho_A)(\varphi - N/(1 - N))}{n} \right\}. \quad (28)$$

Since all terms on the right-hand side of equation (28) are positive under the standard parameterization, $\frac{\partial w_{t+h}^i}{\partial e_t^j} > 0$. This is mainly because w_t^i is a decreasing function of the price of the consumption good P_t ($w_t^i = W_t^i/P_t$) and P_t falls in response to a positive productivity shock to country j . Simply, the real wage is the relative price of leisure to

the price of the consumption good in this model. Hence, in response to the shock decreasing P_t , w_t^i rises. Moreover, using equation (28), we can find $\frac{\partial}{\partial n} \left(\frac{\partial w_{t+h}^i}{\partial e_t^j} \right) = -w_t^h \kappa (1 - \rho_A) (\varphi - N/(1 - N))/n^2 < 0$, meaning that, as n rises, w_t^i goes up by less in response to a positive productivity shock to country j . This is because when there are more countries in the model, a positive productivity shock to country j leads to a smaller fall in P_t (Proposition 3).

Corollary 1. *Under any reasonable parameterization, as the number of countries n increases, the rise in the consumption in country i C_t^i becomes smaller in response to a productivity shock to country j .*

A positive productivity shock to country j causes a rise in the real wage in country i w_t^i (i.e. a fall in the relative price of the consumption goods), and the natural response is an increase in consumption, which can also be seen in equations (14) ($w_t^i = \frac{1-\mu}{\mu} \frac{C_t^i}{1-N_t^i}$) showing that C_t^i is an increasing function of w_t^i . Alternatively, since for consumption smoothing individuals in the more productive country (country j) share some of the additional output with households in less productive countries including country i , C_t^i goes up. Furthermore, because a large n causes a smaller rise in w_t^i according to Proposition 4, C_t^i increases by less when there exist more countries in the model.⁸⁾

8) More precisely, differentiating equation (16) with respect to e_t^j gives $\frac{\partial C_{t+h}^i}{\partial e_t^j} = C_t^h \left\{ \rho_A + \frac{\kappa \varphi (1 - \rho_A)}{n} \right\}$.

Since $\kappa \varphi (1 - \rho_A) > 0$ under the standard parameterization, $\frac{\partial C_{t+h}^i}{\partial e_t^j} > 0$. $\frac{\partial}{\partial n} \left(\frac{\partial C_{t+h}^i}{\partial e_t^j} \right) = -C_t^h \kappa \varphi (1 - \rho_A) / n^2$ and $C_t^h \kappa \varphi (1 - \rho_A) > 0$, which means $\frac{\partial}{\partial n} \left(\frac{\partial C_{t+h}^i}{\partial e_t^j} \right) < 0$.

Corollary 2. *Under standard parameterization, the more countries the model has, the smaller the fall in labor input in country i N_t^i generated by a positive productivity shock to country j .*

Although a rise in the relative price of leisure w_t^i leads households in country i to increase C_t^i and to decrease L_t^i (i.e. raise N_t^i), a rise in w_t^i without a sufficient increase in productivity A_t^i results in a fall in labor demand. That is, labor input in country i N_t^i is a decreasing function of w_t^i and an increasing function of A_t^i from equation (14) ($w_t^i = (1 - \alpha)A_t^i N_t^{i-\alpha}$). Hence, N_t^i falls, since w_t^i goes up and A_t^i does not increase enough to offset the negative impact of the rise in w_t^i on N_t^i . Putting it differently, since households in country j transfer some of the additional output to individuals in less productive countries including country i so as to smooth consumption when a positive productivity hits country j (as already noted), the shock brings about a fall in labor input in less productive countries. Proposition 4 shows that when there are more countries in the model, w_t^i rises by less in response to a positive productivity shock to country j . As a consequence, as the number of countries n grows in the model, N_t^i decreases by less following the shock.⁹⁾

Corollary 3. *Under any reasonable parameterization, when there are more countries in the model, output in country i Y_t^i rises by more or falls by less in response to a productivity shock to country j .*

9) More accurately, by using equation (17) $\frac{\partial N_{t+h}^i}{\partial e_t^j} = N Q^h \frac{\kappa(\rho_A - 1)}{n}$. Since $(\rho_A - 1) < 0$ under the standard parameterization, $\frac{\partial N_{t+h}^i}{\partial e_t^j} < 0$. Therefore, $\frac{\partial}{\partial N} \left(\frac{\partial N_{t+h}^i}{\partial e_t^j} \right) = -N Q^h \kappa(\rho_A - 1) / N^2 > 0$.

It is easy to show that Corollary 3 holds by using the production function ($Y_t^i = A_t^i N_t^{i^{1-\alpha}}$) and Corollary 2. The former shows that output in country i Y_t^i is an increasing function of labor input in country i N_t^i . The latter shows that as the number of countries in the model n rises, N_t^i falls by less. Hence, if the model has more countries, Y_t^i goes up by more or down by less.¹⁰⁾

In short, as the number of countries in the model n grows, a positive productivity shock to country j leads to a larger rise or a smaller fall in the output of country i Y_t^i and a smaller rise in the consumption of country i C_t^i . As a result, the model with more countries generates a higher output correlation and lower consumption correlation compared to the model with less countries, which enables the model with many countries to mitigate the quantity anomaly to some degree. These results are consistent with our initial expectation in the previous section.

III. Quantitative Analysis Using a More General Model

In this section, I provide a quantitative analysis using a more general model than the simple model used in the analytical investigation. This section shows that, even in a more general model, a higher number of countries n is associated with a higher cross-country correlation of output but a lower cross-country correlation of consumption, consistent with the analytical results with the simple model in the previous section.

10) Differentiating equation (18) with respect to c_t^j gives $\frac{\partial Y_{t+h}^i}{\partial c_t^j} = Y_Q^h \left\{ \rho_A - \frac{\kappa(1-\alpha)(1-\rho_A)}{n} \right\}$. Since ρ_A is positive and $\frac{\kappa(1-\alpha)(1-\rho_A)}{n}$ is positive, the sign of $\frac{\partial Y_{t+h}^i}{\partial c_t^j}$ depends on the relative size of $|\rho_A|$ and $\left| \frac{\kappa(1-\alpha)(1-\rho_A)}{n} \right|$. Nevertheless, $\frac{\partial}{\partial n} \left(\frac{\partial Y_{t+h}^i}{\partial c_t^j} \right) = Y_Q^h \kappa(1-\alpha)(1-\rho_A)/n^2 > 0$ because the term $\kappa(1-\alpha)(1-\rho_A) > 0$.

Specifically, I extend the standard two-country international business cycle model of BC to an n -country model.

1. The model

The model¹¹⁾ in this section is a streamlined version of the models of BKK and BC. Specifically, I eliminate the variable representing the level of purely labor-augmenting technical change in the production function from the complete market model of BC.¹²⁾ The main difference between this model and the BC model is the number of countries. That is, the model of BC has two symmetric countries, while this model has $n \geq 2$ symmetric countries.

The preferences for a representative household in each country are described by the following utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t U^i(C_t^i, L_t^i), \quad (29)$$

where $U^i(C_t^i, L_t^i) = \frac{(C_t^{i^\mu} L_t^{i^{1-\mu}})^\gamma}{\gamma}$ and $1 - L_t^i - N_t^i = 0$.

The production function in each country is Cobb-Douglas:

$$Y_t^i = A_t^i K_t^{i^\alpha} N_t^{i^{1-\alpha}}. \quad (30)$$

The productivity follows an AR(1) process:

$$A_t = \Omega A_{t-1} + \mathbf{e}_t, \quad (31)$$

where $A_t = [\ln A_t^1, \ln A_t^2, \dots, \ln A_t^n]'$ and Ω is an $n \times n$ matrix of coefficients. The innovation to A_t is $\mathbf{e}_t = [e_t^1, e_t^2, \dots, e_t^n]'$.

11) The notation used in this section is the same as that in Section II.

12) I also simulate the model with incomplete markets later in this section.

Capital accumulates according to

$$K_{t+1}^i = (1 - \delta)K_t^i + I_t^i - \frac{\phi}{2} \left(\frac{I_t^i}{K_t^i} - \delta \right)^2 K_t^i. \quad (32)$$

World output is allocated to consumption and investment:

$$\sum_{i=1}^n Y_t^i = \sum_{i=1}^n (C_t^i + I_t^i). \quad (33)$$

Competitive equilibrium can be found by solving a planning problem:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \sum_{i=1}^n \frac{1}{n} U^i(C_t^i, L_t^i), \quad (34)$$

subject to equations (32) and (33), and $1 - L_t^i - N_t^i = 0$.¹³⁾

I also follow BKK and BC in assigning the parameter values of the model. Table 2 shows the parameter values. For the coefficient matrix Ω , I assume that off-diagonal elements are all zero¹⁴⁾ and that all diagonal elements have the same value of 0.906.¹⁵⁾ The standard deviation of the innovation e_t^i is set to 0.00852 for all countries. The correlation between all innovation pairs is set to 0.258.

Table 2. Parameter values

β	μ	γ	α	δ	ϕ
0.99	0.334	-1	0.36	0.025	2.5

13) See Appendix B for the first-order conditions for this problem.

14) Although this assumption is mainly for the stationarity and simplicity of the model, many studies find that the off-diagonal elements are close to zero (for details, see Kollmann (1996), Kehoe and Perri (2002), Dmitriev and Roberts (2012), etc.).

15) I also simulate the model with unit-root productivity shocks later in this section.

2. Results

This section presents the business cycle statistics, mainly the cross-country consumption and output correlations, that the model generates according to various values of n . Then the responses of the several variables of country i (say country 1) to a productivity shock to country j (say country 2) when $n=2,3,4$ are presented to study the mechanism of changes in the cross-country correlations.

2.1 Cross-country correlations

The cross-country correlations of output and consumption that are generated by the model according to the various values of the number of countries in the model n are presented in Figure 1. Consistent with the analytical investigation with the simple model in Section 2 and our initial expectation, Figure 1 clearly shows that the more countries the model has, the higher the cross-country correlation of output and the lower the cross-country correlation of consumption. Specifically, the cross-country output correlation is concave in n , and hence as n increases, the slope of (a) in Figure 1 falls. In contrast, the cross-country consumption correlation is convex in n , and therefore the slope of (b) in Figure 1 becomes flatter as n rises.

Figure 1. Cross-country correlations

Note: The correlations are the models' population moments for the Hodrick-Prescott filtered results.

In a nutshell, these results are the same as the analytical results in Section 2 and consistent with our initial expectation. Furthermore, they suggest that adding many countries to international business cycle models helps mitigate the quantity anomaly to some degree as well.

Table 3. Business cycle statistics

Statistics	Data	Two-country	Three-country	Four-country
<i>S.D. relative to GDP in the U.S.</i>				
Consumption	0.83	0.31	0.28	0.27
Investment	3.25	2.77	2.78	2.78
Employment	0.89	0.52	0.54	0.55
Net exports over GDP	0.28	0.20	0.22	0.23
<i>Correlations in the U.S.</i>				
Consumption and GDP	0.88	0.88	0.86	0.85
Investment and GDP	0.93	0.98	0.98	0.97
Net exports over GDP and GDP	-0.53	0.50	0.56	0.59
Saving and investment	0.90	0.97	0.97	0.97
<i>Cross-country correlations</i>				
Output	0.52	0.07	0.11	0.13
Consumption	0.33	0.84	0.81	0.79
Investment	0.43	0.05	0.10	0.12

Notes: S.D. denotes standard deviations. The statistics in the data are based on detrended data using the Hodrick-Prescott filter. Saving is output minus private consumption minus government consumption. The cross-country correlations in the data are for the U.S. and Europe during Q1 1990-Q3 2018. The data for investment (gross fixed capital formation), employment (employed population) and net exports are all from the OECD. The figures in the third, fourth and fifth columns are the models' population moments for the Hodrick-Prescott filtered results.

Although I focus on the cross-country output and consumption correlations, I briefly explain how other primary business cycle statistics change according to various values of n . The business cycle statistics that models with $n = 2, 3, 4$ produce are given in Table 3. Overall, as the number of countries in the model n increases, the business cycle statistics the model yields become closer to the post-1990 data: the standard deviations of investment, employment and net

exports over GDP relative to GDP, the correlation between investment and GDP, and the cross-country correlations of output, consumption and investment all improve. Nevertheless, the standard deviation of consumption relative to GDP, and the correlations between consumption and GDP and between net exports over GDP and GDP become worse as n rises.¹⁶⁾

2.2 Impulse responses

In order to understand how the model generates different values of the cross-country output and consumption correlations as n changes, this section presents the responses of the variables of interest in country 1 to a positive one-standard-deviation productivity shock to country 2.

Figure 2. Responses of variables in country 1 to a positive productivity shock to country 2

The responses of consumption and the real wage in country 1 and the price of the consumption good to a positive productivity shock to country 2 are given in Figure 2. They help understand how the cross-country consumption correlation falls as n rises. As shown in the

16) The correlation between saving and investment becomes slightly lower and closer to the data as n increases. The fall in the correlation, however, is not noticeable. Moreover, as BC noted, saving defined as output minus consumption (basic saving) may not be a good measure of true saving.

previous section, when the model has more countries, the weight of country 2 declines in the world economy. Thus when n is large, the price of the consumption good decreases to a lesser extent following the shock to country 2, which in turn brings about a smaller rise in the real wage in country 1. More intuitively, under complete markets households in country 2 (the more productive country) share some of the additional output with individuals in less productive countries such as country 1, and consumption in country 1 therefore goes up. If the model has many countries, there are more countries with which households in country 2 can share, which leads them to share a smaller amount of the additional output with individuals in each country. As a result, consumption in country 1 goes up by less. Figure 2 clearly show this mechanism.

Figure 3. Responses of variables in country 1 and world real interest rate to a positive productivity shock to country 2

Figure 3 shows the responses of output, labor and capital in country 1 and world real interest rate to a positive productivity shock to country 2, which helps understand the mechanism by which the cross-country output correlation goes up when n is large. Consistent with the analytical results, the output of country 1 goes down by less in response to the shock when the model has more countries, since the shock leads to smaller decreases in labor and capital. To explain, when n is large, the real wage in country 1 rises by less (see (c) in Figure 2), which leads labor demand to fall to a lesser extent. Since the world real interest rate is the intertemporal price of consumption ($\frac{P_t}{\beta E_t[P_{t+1}]}$) and the price falls by less in the case of a large n , the world real interest rate increases by less for the first several periods in response to the shock as n rises. Hence, when n is big, capital in country 1 falls by less. Alternatively, thanks to the shock, country 2 becomes more productive compared to the other countries, and thus it draws capital (mobile factor) from the other countries. When the model has more countries there are more countries from which country 2 draws capital, and thus there is a smaller fall in capital in country 1 following a positive productivity shock to country 2. As a consequence, output in country 1 drops by less as Figure 3 shows.

In short, in the model, which is an n -country version of BC's model, when there are many countries, a positive productivity shock to one country brings about a smaller decrease in output in the other countries, resulting from smaller falls in labor and capital in those countries compared to the case with two countries. It also results in a smaller rise in consumption in the other countries, which is attributed to a smaller fall in the price of final goods and a smaller increase in the real wage compared to the two-country case. These responses to the shock enable the cross-country output correlation to be higher and the cross-country consumption correlation to be lower than when the model includes only two countries. Finally, these results are consistent with the analytical results using the simple model in the previous section and our initial

expectation. From these results, we can infer that the number of countries in an international business cycle model matters and we should favor models with many countries to properly explain international business cycles after the 1990s.

3. Further experiments

In this section, I conduct several further experiments regarding the persistence of productivity and the structure of asset markets. This is because BC emphasizes that random walk productivity (unit-root in productivity) and restricting asset markets (incomplete markets) are important in explaining cross-country consumption and output correlations. I thus consider random walk productivity in the model and incomplete markets where asset trade is restricted to bonds only.

3.1 Complete markets with random walk productivity

The cross-country output and consumption correlations generated by the models with complete markets and random walk productivity according to changes in values of n are shown in Figure 4. Consistent with the results in the previous section, as n rises, the cross-country output correlation goes up and the cross-country consumption correlation falls.

Figure 4. Cross-country correlations under complete markets with unit-root shocks

Note: The correlations are the models' population moments for the Hodrick-Prescott filtered results.

3.2 Incomplete markets with trend stationary productivity

If we restrict asset trade to noncontingent bonds only, then the budget constraint for each country in period t is

$$P_t^B b_{t+1}^i + C_t^i + I_t^i = Y_t^i + b_t^i, \quad (35)$$

where b_t denotes the bond and P_t^B is the price of the one-period discount bond. Since the net supply of bonds is zero, the bond market clearing condition is

$$\sum_{i=1}^n \frac{1}{n} b_t^i = 0. \quad (36)$$

The first-order conditions for the model with incomplete markets are provided in Appendix B.

Figure 5. Cross-country correlations under incomplete markets with trend stationary shocks

Note: The correlations are the models' population moments for the Hodrick-Prescott filtered results.

Figure 5 provides the cross-country output and consumption correlations produced by the models with incomplete markets and trend stationary productivity under various values of n . The

cross-country output correlation increases and the cross-country consumption correlation decreases when the model has more countries, which is consistent with the earlier results.

3.3 Incomplete markets with random walk productivity

Finally, I consider a model with incomplete markets and random walk productivity. In contrast to the previous results, the cross-country output correlation falls and the cross-country consumption correlation rises as n increases. To explain, in the bond economy agents can smooth consumption using only bonds. That is, when a positive productivity shock hits a certain country, less productive countries accumulate bonds to smooth consumption, and hence their consumption falls and their labor supply rises (i.e. their output goes up). As already discussed, when the model has more countries, the weight of each country in the world economy becomes lower. In the case of a large n , the price of the bond P_t^B falls by less in response to a positive productivity shock to a certain country, which leads less productive countries to accumulate fewer bonds. As a consequence, when n is large, their consumption falls by less and their output increases by less, which brings about a higher cross-country consumption correlation and a lower cross-country output correlation than when n is small.

Nevertheless, the model generates more reliable cross-country correlations when n is large. Specifically, when $n=2$ the cross-country output correlation is 0.55, when $n=15$ it is 0.44, and it is 0.52 in the data. Hence, as n grows the correlation that the model yields becomes slightly worse compared to the data. The cross-country consumption correlation, however, improves to a great degree as n increases. In the case of $n=2$ the correlation is -0.20, in the case of $n=15$ it is 0.09, and it is 0.33 in the data.

Figure 6. Cross-country correlations under incomplete markets with unit-root shocks

Note: The correlations are the models' population moments for the Hodrick-Prescott filtered results.

IV. Conclusion

This paper first shows that since the 1990s the key international business cycle statistics in the data have changed with the emergence of a number of countries as additional global players: the cross-country output correlation between the U.S. and Europe increased and the cross-country consumption correlation between them slightly fell. In order to capture these changes, this paper constructs international business cycle models with many countries, rather than with two countries only. Both the analytical investigation with the simple model and the quantitative study with the more general model show that the number of countries in international business cycle models matters in explaining the changes. Specifically, adding many countries raises the cross-country correlation of output and decreases the cross-country correlation of consumption in line with the changes, which also helps to mitigate the quantity anomaly to some degree.

Although this paper shows that considering many countries in international business cycle models is very useful, there is still room for improvement. This paper only considers standard models with a

single consumption good. Hence, considering differentiated consumption goods, non-traded goods and the distribution sector may explain international business cycles better, since many studies have argued that these elements are useful in explaining international business cycles. Finally, if we introduce monetary and fiscal policies into the n -country model in this paper, it would be possible to analyze the spillover effects of foreign policies on domestic economy more accurately since the model explains international macroeconomic interactions better than standard two-country models. Even though including these elements would be interesting, I leave this for future research.

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Appendix

A. Finding policy functions

First consider the case of $n = 2$. Then the corresponding log-linearized forms of equations (11)-(13) are

$$\chi \hat{C}_t^1 - \xi \hat{N}_t^1 = \chi \hat{C}_t^2 - \xi \hat{N}_t^2, \quad (\text{A.1})$$

$$\hat{C}_t^1 = \hat{A}_t^1 - \varphi \hat{N}_t^1, \quad (\text{A.2})$$

$$\hat{C}_t^2 = \hat{A}_t^2 - \varphi \hat{N}_t^2, \quad (\text{A.3})$$

$$\hat{A}_t^1 + (1 - \alpha) \hat{N}_t^1 + \hat{A}_t^2 + (1 - \alpha) \hat{N}_t^2 = \hat{C}_t^1 + \hat{C}_t^2, \quad (\text{A.4})$$

with $\chi = \mu\gamma - 1$, $\xi = \frac{N\gamma(1-\mu)}{1-N}$ and $\varphi = \alpha + \frac{N}{1-N}$.

I guess the following laws of motion for $\hat{C}_t^i$ and $\hat{N}_t^i$:

$$\hat{C}_t^1 = \eta_1^1 \hat{A}_t^1 + \eta_1^2 \hat{A}_t^2, \quad (\text{A.5})$$

$$\hat{C}_t^2 = \eta_2^1 \hat{A}_t^1 + \eta_2^2 \hat{A}_t^2, \quad (\text{A.6})$$

$$\hat{N}_t^1 = \nu_1^1 \hat{A}_t^1 + \nu_1^2 \hat{A}_t^2, \quad (\text{A.7})$$

$$\hat{N}_t^2 = \nu_2^1 \hat{A}_t^1 + \nu_2^2 \hat{A}_t^2. \quad (\text{A.8})$$

Inserting the above in equation (A.1) yields

$$\chi(\eta_1^1 \hat{A}_t^1 + \eta_1^2 \hat{A}_t^2) - \xi(\nu_1^1 \hat{A}_t^1 + \nu_1^2 \hat{A}_t^2) = \chi(\eta_2^1 \hat{A}_t^1 + \eta_2^2 \hat{A}_t^2) - \xi(\nu_2^1 \hat{A}_t^1 + \nu_2^2 \hat{A}_t^2). \quad (\text{A.9})$$

This equation should hold at all points in the state-space, i.e. for all combinations of $\hat{A}_t^1$ and $\hat{A}_t^2$. Setting $\hat{A}_t^2 = 0$ gives

$$\chi\eta_1^1\hat{A}_t^1 - \xi\nu_1^1\hat{A}_t^1 = \chi\eta_2^1\hat{A}_t^1 - \xi\nu_2^1\hat{A}_t^1. \quad (\text{A.10})$$

And setting $\hat{A}_t^1 = 0$ gives

$$\chi\eta_1^2\hat{A}_t^2 - \xi\nu_1^2\hat{A}_t^2 = \chi\eta_2^2\hat{A}_t^2 - \xi\nu_2^2\hat{A}_t^2. \quad (\text{A.11})$$

By equations (A.10) and (A.11),

$$\chi\eta_1^1 - \xi\nu_1^1 = \chi\eta_2^1 - \xi\nu_2^1, \quad (\text{A.12})$$

$$\chi\eta_1^2 - \xi\nu_1^2 = \chi\eta_2^2 - \xi\nu_2^2. \quad (\text{A.13})$$

Similarly, inserting the guesses in equations (A.2) and (A.3), and setting $\hat{A}_t^2 = 0$ and $\hat{A}_t^1 = 0$ gives

$$\eta_1^1 = 1 - \varphi\nu_1^1, \quad (\text{A.14})$$

$$\eta_1^2 = -\varphi\nu_1^2, \quad (\text{A.15})$$

$$\eta_2^2 = 1 - \varphi\nu_2^2, \quad (\text{A.16})$$

$$\eta_2^1 = -\varphi\nu_2^1. \quad (\text{A.17})$$

Inserting the guesses in equation (A.4), and setting $\hat{A}_t^2 = 0$ and $\hat{A}_t^1 = 0$ yields

$$1 + (1 - \alpha)\nu_1^1 + (1 - \alpha)\nu_2^1 = \eta_1^1 + \eta_2^1, \quad (\text{A.18})$$

$$1 + (1 - \alpha)\nu_1^2 + (1 - \alpha)\nu_2^2 = \eta_1^2 + \eta_2^2. \quad (\text{A.19})$$

We have eight unknown coefficients (η_1^1 , η_1^2 , η_2^1 , η_2^2 , ν_1^1 , ν_1^2 , ν_2^1 and ν_2^2) and eight equations (equations (A.12)-(A.19)) and thus we can solve for the coefficients of the policy rules. Specifically, the coefficients are

$$\eta_1^1 = \eta_2^2 = 1 - \frac{\kappa\varphi}{2}, \eta_2^1 = \eta_1^2 = \frac{\kappa\varphi}{2}, \nu_1^1 = \nu_2^2 = \frac{\kappa}{2}, \nu_2^1 = \nu_1^2 = -\frac{\kappa}{2},$$

with $\kappa = \frac{\chi}{\xi + \chi\varphi}$. Finally, the policy rules are

$$\hat{C}_t^1 = (1 - \kappa\varphi)\hat{A}_t^1 + \frac{\kappa\varphi}{2}(\hat{A}_t^1 + \hat{A}_t^2), \quad (\text{A.20})$$

$$\hat{C}_t^2 = (1 - \kappa\varphi)\hat{A}_t^2 + \frac{\kappa\varphi}{2}(\hat{A}_t^1 + \hat{A}_t^2), \quad (\text{A.21})$$

$$\hat{N}_t^1 = \kappa\hat{A}_t^1 - \frac{\kappa}{2}(\hat{A}_t^1 + \hat{A}_t^2), \quad (\text{A.22})$$

$$\hat{N}_t^2 = \kappa\hat{A}_t^2 - \frac{\kappa}{2}(\hat{A}_t^1 + \hat{A}_t^2). \quad (\text{A.23})$$

Similarly, we can obtain the policy rules when $n = 3$. They are

$$\hat{C}_t^1 = (1 - \kappa\varphi)\hat{A}_t^1 + \frac{\kappa\varphi}{3}(\hat{A}_t^1 + \hat{A}_t^2 + \hat{A}_t^3), \quad (\text{A.24})$$

$$\hat{C}_t^2 = (1 - \kappa\varphi)\hat{A}_t^2 + \frac{\kappa\varphi}{3}(\hat{A}_t^1 + \hat{A}_t^2 + \hat{A}_t^3), \quad (\text{A.25})$$

$$\hat{C}_t^3 = (1 - \kappa\varphi)\hat{A}_t^3 + \frac{\kappa\varphi}{3}(\hat{A}_t^1 + \hat{A}_t^2 + \hat{A}_t^3), \quad (\text{A.26})$$

$$\hat{N}_t^1 = \kappa\hat{A}_t^1 - \frac{\kappa}{3}(\hat{A}_t^1 + \hat{A}_t^2 + \hat{A}_t^3), \quad (\text{A.27})$$

$$\hat{N}_t^2 = \kappa\hat{A}_t^2 - \frac{\kappa}{3}(\hat{A}_t^1 + \hat{A}_t^2 + \hat{A}_t^3), \quad (\text{A.28})$$

$$\hat{N}_t^3 = \kappa\hat{A}_t^3 - \frac{\kappa}{3}(\hat{A}_t^1 + \hat{A}_t^2 + \hat{A}_t^3). \quad (\text{A.29})$$

Therefore, we can generalize the policy rules when there are n countries.

$$\hat{C}_t^i = (1 - \kappa\varphi)\hat{A}_t^i + \frac{\kappa\varphi}{n} \sum_{l=1}^n \hat{A}_t^l, \quad (\text{A.30})$$

$$\hat{N}_t^i = \kappa\hat{A}_t^i - \frac{\kappa}{n} \sum_{l=1}^n \hat{A}_t^l. \quad (\text{A.31})$$

By using $\hat{z}_t = \frac{z_t - z}{z}$, equations (A.30) and (A.31) can be written as

$$C_t^i = C + C \left\{ (1 - \kappa\varphi)\hat{A}_t^i + \frac{\kappa\varphi}{n} \sum_{l=1}^n \hat{A}_t^l \right\}, \quad (\text{A.32})$$

$$N_t^i = N + N \left\{ \kappa\hat{A}_t^i - \frac{\kappa}{n} \sum_{l=1}^n \hat{A}_t^l \right\}. \quad (\text{A.33})$$

B. First-order conditions of the model in the quantitative analysis

The economy of the model with complete markets in the quantitative analysis is described by the following equations together with the equations for the disturbance to technology:

$$P_t = \mu C_t^{i^{\mu\gamma-1}} L_t^{i^{(1-\mu)}}, \text{ for } i = 1, 2, \dots, n, \quad (\text{B.1})$$

$$W_t^i = (1 - \mu) C_t^{i^{\mu\gamma}} L_t^{i^{(1-\mu)-1}}, \text{ for } i = 1, 2, \dots, n, \quad (\text{B.2})$$

$$W_t^i = (1 - \alpha) P_t A_t^i K_t^{i^\alpha} N_t^{i^{-\alpha}}, \text{ for } i = 1, 2, \dots, n, \quad (\text{B.3})$$

$$P_t = \lambda_t^i \left\{ 1 - \phi \left(\frac{I_t^i}{K_t^i} - \delta \right) \right\}, \text{ for } i = 1, 2, \dots, n, \quad (\text{B.4})$$

$$\begin{aligned} \lambda_t^i = & \beta E_t \left[\lambda_{t+1}^i \left\{ -\frac{\phi}{2} \left(\frac{I_{t+1}^i}{K_{t+1}^i} - \delta \right)^2 + \phi \left(\frac{I_{t+1}^i}{K_{t+1}^i} - \delta \right) \frac{I_{t+1}^i}{K_{t+1}^i} + (1 - \delta) \right\} \right] \\ & + \alpha \beta E_t \left[P_{t+1} A_{t+1}^i K_{t+1}^{i^{\alpha-1}} N_{t+1}^{i^{1-\alpha}} \right], \text{ for } i = 1, 2, \dots, n, \end{aligned} \quad (\text{B.5})$$

$$0 = 1 - L_t^i - N_t^i, \text{ for } i = 1, 2, \dots, n, \quad (\text{B.6})$$

$$K_{t+1}^i = (1 - \delta)K_t^i + I_t^i - \frac{\phi}{2} \left(\frac{I_t^i}{K_t^i} - \delta \right)^2 K_t^i, \text{ for } i = 1, 2, \dots, n, \quad (\text{B.7})$$

$$\sum_{i=1}^n A_t^i K_t^{i^\alpha} N_t^{i^{1-\alpha}} = \sum_{i=1}^n (C_t^i + I_t^i). \quad (\text{B.8})$$

where P_t , W_t^i and λ_t^i are Lagrangian multipliers.

The economy of the model with incomplete markets is described by equations (B.2) and (B.6)-(B.8), and by the following equations together with the equations for the disturbance to technology:

$$P_t^i = \mu C_t^{i^{\mu\gamma-1}} L_t^{i^{(1-\mu)}}, \text{ for } i = 1, 2, \dots, n, \quad (\text{B.9})$$

$$W_t^i = (1 - \alpha)P_t^i A_t^i K_t^{i^\alpha} N_t^{i^{-\alpha}}, \text{ for } i = 1, 2, \dots, n, \quad (\text{B.10})$$

$$P_t^i = \lambda_t^i \left\{ 1 - \phi \left(\frac{I_t^i}{K_t^i} - \delta \right) \right\}, \text{ for } i = 1, 2, \dots, n, \quad (\text{B.11})$$

$$\begin{aligned} \lambda_t^i = \beta E_t \left[\lambda_{t+1}^i \left\{ -\frac{\phi}{2} \left(\frac{I_{t+1}^i}{K_{t+1}^i} - \delta \right)^2 + \phi \left(\frac{I_{t+1}^i}{K_{t+1}^i} - \delta \right) \frac{I_{t+1}^i}{K_{t+1}^i} + (1 - \delta) \right\} \right] \\ + \alpha \beta E_t \left[P_{t+1}^i A_{t+1}^i K_{t+1}^{i^{\alpha-1}} N_{t+1}^{i^{1-\alpha}} \right], \text{ for } i = 1, 2, \dots, n, \end{aligned} \quad (\text{B.12})$$

$$P_t^B = \beta E_t \left[\frac{P_{t+1}^i}{P_t^i} \right], \text{ for } i = 1, 2, \dots, n, \quad (\text{B.13})$$

$$\sum_{i=1}^n \frac{1}{n} b_t^i = 0, \quad (\text{B.14})$$

$$P_t^B b_{t+1}^j + C_t^j + I_t^j = Y_t^j + b_t^j, \text{ for } j = 2, \dots, n. \quad (\text{B.15})$$

<Abstract in Korean>

다국모형을 이용한 국제경기변동 분석

김명현*

1990년대까지는 미국과 유럽을 상정한 2국모형으로 세계경제를 설명하는 것이 타당하다고 볼 수 있었다. 그러나 1990년대 이후에는 중국, 러시아 등 신흥국이 부상함에 따라 2국모형을 이용한 국제경기변동 등 세계경제 분석의 현실성 및 설득력이 충분하다고 보기 어렵게 되었다. 아울러 세계경제 환경이 변하면서 국가간 생산 상관관계는 강화된 반면 소비 상관관계는 소폭 약화되는 등 국제경기변동도 이전과는 다른 모습을 보이고 있다. 이에 따라 본고는 표준적인 2국모형을 다국모형으로 확장할 경우 2국모형보다 1990년대 이후의 국제경기변동의 변화를 잘 설명할 수 있음을 보였다. 단순한 모형을 이용한 이론분석과 보다 일반적인 모형을 이용한 수량분석 모두에서 국제경기변동모형에 국가 개수가 늘어날수록 국가간 생산 상관계수는 상승하고 소비 상관계수는 하락하는 등 1990년대 이후의 국제경기변동을 보다 잘 설명하는 것으로 나타났다.

핵심 주제어: 국제경기변동, 다국모형, 국가 개수, 생산 상관계수, 소비 상관계수

JEL Classification: F40, F41, F44

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한국은행 경제연구원에서는 Working Paper인 『BOK 경제연구』를 수시로 발간하고 있습니다. 『BOK 경제연구』는 주요 경제 현상 및 정책 효과에 대한 직관적 설명 뿐 아니라 깊이 있는 이론 또는 실증 분석을 제공함으로써 엄밀한 논증에 초점을 두는 학술논문 형태의 연구이며 한국은행 직원 및 한국은행 연구용역사업의 연구 결과물이 수록되고 있습니다. 『BOK 경제연구』는 한국은행 경제연구원 홈페이지(<http://imer.bok.or.kr>)에서 다운로드하여 보실 수 있습니다.

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26	고령화가 대외투자에 미치는 영향	임진수 · 김영래
27	인구고령화가 가계의 자산 및 부채에 미치는 영향	조세형 · 이용민 · 김정훈
28	인구고령화에 따른 우리나라 산업구조 변화	강종구
29	인구구조 변화와 재정	송호신 · 허준영
30	인구고령화가 노동수급에 미치는 영향	이철희 · 이지은
31	인구 고령화가 금융산업에 미치는 영향	윤경수 · 차재훈 · 박소희 · 강선영
32	금리와 은행 수익성 간의 관계 분석	한재준 · 소인환
33	Bank Globalization and Monetary Policy Transmission in Small Open Economies	Inhwan So
34	기존 경영자 관리인(DIP) 제도의 회생기업 경영성과에 대한 영향	최영준
35	Transmission of Monetary Policy in Times of High Household Debt	Youngju Kim · Hyunjoon Lim
제2018 -1	4차 산업혁명과 한국의 혁신역량: 특허자료를 이용한 국가기술별 비교 분석, 1976-2015	이지홍 · 임현경 · 정대영
2	What Drives the Stock Market Comovements between Korea and China, Japan and the US?	Jinsoo Lee · Bok-Keun Yu
3	Who Improves or Worsens Liquidity in the Korean Treasury Bond Market?	Jieun Lee

제2018-4	Establishment Size and Wage Inequality: The Roles of Performance Pay and Rent Sharing	Sang-yoon Song
5	가계대출 부도요인 및 금융업권별 금융취약성: 자영업 차주를 중심으로	정호성
6	직업훈련이 청년취업을 제고에 미치는 영향	최충 · 김남주 · 최광성
7	재고투자와 경기변동에 대한 동학적 분석	서병선 · 장근호
8	Rare Disasters and Exchange Rates: An Empirical Investigation of Korean Exchange Rates under Tension between the Two Koreas	Cheolbeom Park · Suyeon Park
9	통화정책과 기업 설비투자 - 자산가격경로와 대차대조표경로 분석 -	박상준 · 육승환
10	Upgrading Product Quality: The Impact of Tariffs and Standards	Jihyun Eum
11	북한이탈주민의 신용행태에 관한 연구	정승호 · 민병기 · 김주원
12	Uncertainty Shocks and Asymmetric Dynamics in Korea: A Nonlinear Approach	Kevin Larcher · Jaebeom Kim · Youngju Kim
13	북한경제의 대외개방에 따른 경제적 후생 변화 분석	정혁 · 최창용 · 최지영
14	Central Bank Reputation and Inflation-Unemployment Performance: Empirical Evidence from an Executive Survey of 62 Countries	In Do Hwang
15	Reserve Accumulation and Bank Lending: Evidence from Korea	Youngjin Yun
16	The Banks' Swansong: Banking and the Financial Markets under Asymmetric Information	Jungu Yang

제2018-17	E-money: Legal Restrictions Theory and Monetary Policy	Ohik Kwon · Jaevin Park
18	글로벌 금융위기 전·후 외국인의 채권투자 결정요인 변화 분석: 한국의 사례	유복근
19	설비자본재 기술진보가 근로유형별 임금 및 고용에 미치는 영향	김남주
20	Fixed-Rate Loans and the Effectiveness of Monetary Policy	Sung Ho Park
21	Leverage, Hand-to-Mouth Households, and MPC Heterogeneity: Evidence from Korea	Sang-yoon Song
22	선진국 수입수요가 우리나라 수출에 미치는 영향	최문정 · 김경근
23	Cross-Border Bank Flows through Foreign Branches: Evidence from Korea	Youngjin Yun
24	Accounting for the Sources of the Recent Decline in Korea's Exports to China	Moon Jung Choi · Kei-Mu Yi
25	The Effects of Export Diversification on Macroeconomic Stabilization: Evidence from Korea	Jinsoo Lee · Bok-Keun Yu
26	Identifying Uncertainty Shocks due to Geopolitical Swings in Korea	Seohyun Lee · Inhwan So · Jongrim Ha
27	Monetary Policy and Income Inequality in Korea	Jongwook Park
28	How the Financial Market Can Dampen the Effects of Commodity Price Shocks	Myunghyun Kim
29	Which External Shock Matters in Small Open Economies? US Economic Policy Uncertainty vs. Global Risk Aversion	Youngju Kim · Hyunjoon Lim
30	Do Korean Exports Have Different Patterns over Different Regimes?: New Evidence from STAR-VECM	Sei-Wan Kim · Moon Jung Choi
31	기술진보와 청년고용	심명규 · 양희승 · 이서현

제2018-32	북한지역 장기주택수요 및 연관 주택건설투자 추정	이주영
33	기업규모간 임금격차 원인 분석	송상윤
34	우리나라 고용구조의 특징과 과제	장근호
35	창업의 장기 고용효과: 시군구 자료 분석	조성철 · 김기호
36	수출입과 기업의 노동수요	음지현 · 박진호 · 최문정
37	청년실업의 이력현상 분석	김남주
38	노동시장 이중구조와 노동생산성: OECD 국가를 중심으로	최충 · 최광성 · 이지은
39	한국과 일본의 청년실업 비교분석 및 시사점	박상준 · 김남주 · 장근호
40	노동시장의 이중구조와 정책대응: 해외사례 및 시사점	전병유 · 황인도 · 박광용
41	최저임금이 고용구조에 미치는 영향	송헌재 · 임현준 · 신우리
42	최저임금과 생산성: 우리나라 제조업의 사례	김규일 · 육승환
43	Transmission of U.S. Monetary Policy to Commodity Exporters and Importers	Myunghyun Kim
44	Determinants of Capital Flows in the Korean Bond Market	Soohyon Kim
45	Central Bank Credibility and Monetary Policy	Kwangyong Park
46	통화정책이 자본유출입에 미치는 영향: 행태방정식 분석	이명수 · 송승주

제2018-47	Commodities and International Business Cycles	Myunghyun Kim
제2019-1	Deciphering Monetary Policy Board Minutes through Text Mining Approach: The Case of Korea	Ki Young Park • Youngjoon Lee • Soohyon Kim
2	The Impacts of Macroeconomic News Announcements on Intraday Implied Volatility	Jieun Lee • Doojin Ryu
3	Taking a Bigger Slice of the Global Value Chain Pie: An Industry-level Analysis	Chong-Sup Kim • Seungho Lee • Jihyun Eum
4	Trend Growth Shocks and Asset Prices	Nam Gang Lee
5	Uncertainty, Attention Allocation and Monetary Policy Asymmetry	Kwangyong Park
6	Central Bank Digital Currency and Financial Stability	Ohik Kwon
7	은행의 수익 및 자산구조를 반영한 통화정책 위험선호경로	김의진 • 정호성
8	혁신기업에 대한 산업금융 지원: 이론모형 분석	강경훈 • 양준구
9	가계부채 제약하의 통화정책: 2주체 거시 모형(TANK)에서의 정량적 분석	정용승 • 송승주
10	Alchemy of Financial Innovation: Securitization, Liquidity and Optimal Monetary Policy	Jungu Yang
11	Measuring Monetary Policy Surprises Using Text Mining: The Case of Korea	Youngjoon Lee • Soohyon Kim • Ki Young Park
12	Tracking Uncertainty through the Relative Sentiment Shift Series	Seohyun Lee • Rickard Nyman
13	Intra-firm and Arm's Length Trade during the Global Financial Crisis: Evidence from Korean Manufacturing Firms	Moon Jung Choi • Ji Hyun Eum

제2019-14	특허자료를 이용한 우리나라 지식전파의 지역화 분석	이지홍 · 남윤미
15	Overhead Labour and Skill-Biased Technological Change: The Role of Product Diversification	Choong Hyun Nam
16	Does the Number of Countries in an International Business Cycle Model Matter?	Myunghyun Kim