ESSAYS ON INTERNATIONAL REAL BUSINESS CYCLE MODELS AND BAYESIAN ESTIMATION

By

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To my wife, my parents, and my daughter. I know I am never alone.

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CHAPTER I

Estimating Emerging Market Business Cycles: Does Heterogeneity Matter?

Introduction

Recent macroeconomic studies on emerging economies have extensively discussed the impact of permanent productivity shocks on business cycles. The permanent income hypothesis (PIH) implies that permanent and transitory shocks on income have distinct effects on households' consumption and saving decision. Decomposing the effects of permanent and transitory shocks for different countries can help us to better understand the structures of different economies, especially the developing countries. One approach in the recent macroeconomic research on developing countries has implemented this idea by introducing permanent shocks to the standard small open economy real business cycles models. According to Aguiar and Gopinath (2007), a standard one-good SOE model with a permanent productivity shock is sufficient to explain the stylized facts of the developing countries that are considered difficult for the small open economy RBC models, including frequent trade balance reversals and high volatility of consumption relative to output. According to their estimates of the persistence and volatility of the shocks, Aguiar and Gopinath (2007) conclude that the permanent shock dominates the households' consumption and saving behaviors in the developing countries.

Although different implications of permanent and transitory productivity shocks are important in explaining the facts of the low-income countries, very few studies conduct a thorough analysis for a large set of developed and developing countries. There are mainly two caveats in the current literature. First, parameters in the model are usually not fully estimated. Many papers only estimate a small subset of parameters, and calibrate the rest in a somehow cavalier manner. For example, in the estimation in Aguiar and Gopinath (2007), the authors fix the parameters for the preference and production functions. Moreover, those parameter values are the same for Canada and Mexico. It is very likely that the heterogeneity of those structural parameters may introduce bias into the estimates. Second, developing countries are generally represented by a small group of countries, especially Latin American countries. For instance, Aguiar and Gopinath (2007) use Mexico to represent developing countries in their analysis. Also, Garcia-Cicco, Pancrazi, and Uribe (2010) develop a small-open economy model with financial frictions, and argue that the key factor is the financial frictions. But their results are only based on Argentine data. Moreover, Chang and Fernandez (2010) conduct a Bayesian estimation using Aguiar and Gopinath (2007)'s model, as well as the financial friction model, and their result is generally in favor of the latter paper. Yet their estimation is only for Mexico as well. Although most Latin American countries are typical developing countries, the arguments on developing countries can be misleading if we mainly draw our conclusion on Latin American countries, due to the heterogenous nature of developing countries.

In this paper, I re-examine the role of permanent and transitory productivity shocks, taking into account of the heterogeneity of every parameter in the small open economy model for a large group of countries. My estimations take advantage of the rapid development of the Bayesian techniques. In my benchmark estimation, I formally estimate the parameters of the exogenous shock processes and the structural parameters for each country. The result of the benchmark estimation shows the level of uniformity of each parameter across countries. I then conduct two alternative estimations. In the first alternative, I only estimate the exogenous shock parameters with other parameters fixed; and in the second alternative, I estimate the labor income share and shock parameters, which are the essential parameters for the variance decomposition. Then I compare the variance decomposition resulted from the benchmark estimation and the two alternatives. I employ the dataset of Aguiar and Gopinath (2007). Therefore I can ensure that my results are comparable to theirs.

My results are of interest in two senses. First, my benchmark estimation shows that several parameters exhibit moderate heterogeneity across countries. For example, the labor income share ranges from 0.48 (Slovakia) to 0.81 (Portugal, Switzerland). The common practice that assumes highly uniform labor shares may be inappropriate. Moreover, I find the capital adjustment cost is higher in the developing countries than in the developed countries. A high capital adjustment cost would impede investment in the emerging economy, and thus reduce the consumption smoothing behavior of the household, which leads to higher consumption volatility. Also, the heterogeneity of parameter values reminds us that we need extra caution in our calibration, especially for developing countries. Second, the comparison of my benchmark estimation and the two alternatives shows that bias in variance decomposition does exist, if we do not fully estimate the model. The two alternatives both underestimate the effects of the permanent part of the TFP shocks. Moreover, the bias is larger for developing countries. The results of my variance decomposition in my benchmark estimation also confirms Aguiar and Gopinath (2007)'s conclusion that permanent productivity shocks are more important in developing countries.

This paper is also related to a recent literature on estimation of open economy models with Bayesian methods, including Lubik and Schorfheide (2006), and An and Schorfheide (2007). The Bayesian methods for dynamic stochastic models provide a formal, likelihood-based way to estimate the full model.

The rest of the paper is organized as follows. In the next section I outline the dynamic stochastic model for my empirical analysis. In Section 3 I discuss the empirical strategies and data. In section 4 I present the estimation results. Variance decomposition is also conducted in this section. In section 5 I conclude.

Model

The model in our study is a standard small open economy (SOE) RBC model augmented with both stationary and non-stationary TFP shocks, which is the same as the model in Aguiar and Gopinath (2007). Specifically, the production function takes the form

$$Y_t = e^{z_t} K_t^{1-\alpha} (\Gamma_t L_t)^{\alpha}, \tag{I.1}$$

where α denotes the labor share in the production, Y_t denotes the output in period t, K_t denotes the capital stock in period t, L_t denotes the labor input in period t, z_t represents the transitory TFP shock, and Γ_t represents the permanent productivity shock that follows

$$\ln \Gamma_t = \ln \Gamma_{t-1} + \ln g_t$$

$$\ln g_t = (1-\rho_g) \ln \mu_g + \rho_g \ln g_{t-1} + \varepsilon_t^g,$$

where $|\rho_g| < 1$, ε_t^g is a *iid* draw from a normal distribution $N(0, \sigma_g)$. The parameter μ_g denotes the deterministic long-run growth rate of the productivity.

The transitory productivity shock z_t follows an AR(1) process

$$z_t = \rho_z z_{t-1} + \varepsilon_t^z, \tag{I.2}$$

where $|\rho_z| < 1$, ε_t^z is a *iid* draw from a normal distribution $N(0, \sigma_z)$.

The household has a Cobb-Douglas type of utility function taking the form

$$u_t = (C_t^{\gamma}(1 - L_t)^{1-\gamma})^{1-\sigma}/(1 - \sigma), \tag{I.3}$$

where γ denotes the consumption share in the utility, and σ controls the intertemporal rate of substitution.

The household maximizes her expected utility, subject to the production function and the following budget constraint

$$C_t + K_{t+1} = Y_t + (1 - \delta)K_t - \frac{\phi}{2}(\frac{K_{t+1}}{K_t} - \mu_g)^2 K_t - B_t + q_t B_{t+1}, \tag{I.4}$$

where the capital depreciation rate is δ, and the capital adjustment cost is controlled by ϕ. The international financial market only trades one asset: a one-period, risk-free bond. The bond sold at period t matures at period $t+1$ and has a face value of 1. The variable q_t is the bond price in the time t, and B_t denotes the stock of bonds which may either be positive or negative. Following the specification in Schmitt-Grohe and Uribe (2003), I have

$$\frac{1}{q_t} \equiv 1 + r_t \equiv 1 + r^* + \psi[e^{\frac{B_{t+1}}{\Gamma_t} - b} - 1], \tag{I.5}$$

where r^* is the world interest rate, b is the debt level at steady state, and ψ controls the elasticity of the interest rate to the debt level.

Estimation and Data

Estimation: Parameters and Techniques

In this paper, I conduct three estimations, including the benchmark estimation and two alternative estimations. In the benchmark estimation, I estimate all the parameters in the model for all the countries. Hence I can directly check the heterogeneity of each parameter across countries. Then I conduct two alternative estimations. In the first alternative estimation, I only estimate the shock parameters, and set all the other parameters the same as in Aguiar and Gopinath (2007). And in the second estimation, I add the parameter α into the estimation. The parameter α is essential in the calculation of variance decomposition, which also shows a moderate degree of heterogeneity across different countries in the benchmark estimation. Therefore, by comparing the results from the benchmark estimation and the first alternative one, we can find out how much bias will be introduced by the calibration that every country has the same labor income share value. Moreover, by estimating α in the second alternative estimation, we can see how much bias can be corrected by including just one additional parameter.

Bayesian estimation techniques developed in recent years become increasingly popular in the current literature on empirical analysis of macroeconomic models. This likelihood-based approach allows the researchers to estimate both the structural parameter of preferences and technology simultaneously with the stochastic processes of the shocks to the economic environment.

Bayesian econometricians regard the parameters in the model as random variables, and the inference of them should both depend on the voice of the researcher (prior), and the voice of the data (likelihood). This view is different from the traditional frequentists' view that the estimates should converge to the "true" parameter value.

In the Bayesian view, the joint probability of the parameter and data should satisfy

$$p(X,\mu) = L(X|\mu)\pi(\mu),$$

$$p(X,\mu) = P(\mu|X)p(X),$$

where X denotes the data, μ denotes the parameter, $L(X|\mu)$ denotes the likelihood of the data for given parameter value, $\pi(\mu)$ denotes the prior distribution of the parameters and $p(X)$ denotes the unconditional distribution of the data. Therefore according to Bayes' rule, I have

$$P(\mu|X) = L(X|\mu)\pi(\mu)/p(X) \propto L(X|\mu)\pi(\mu), \tag{I.6}$$

where $P(\mu|X)$ is called the "posterior distribution", which is the central focus of Bayesian analyses. In order to report the marginal distribution of each parameter, we have to integrate out other parameters by

$$P(\mu_i|X) = \int_{\mu_1}\int_{\mu_2}...\int_{\mu_{i-1}}\int_{\mu_{i+1}}...\int_{\mu_k} P(\mu|X)d\mu_1 d\mu_2 d\mu_4...d\mu_k. \tag{I.7}$$

The numerical routine for obtaining the posterior moments of the parameters is the Random-Walk Metropolis algorithm (An and Schorfheide 2006).

The Prior Distribution: The Labor Income Share And Other Parameters

The choice of prior distribution is essential to our Bayesian estimation, as the posterior probability relies upon both prior probability and likelihood. Parameters' prior distribution reflects the information from past data, casual observation, or considerations based on economic theories. Therefore I carefully choose the parameters' prior distribution from the data as well as the existing literature.

In most studies, labor income share is set to be between 0.66 and 0.70. But this conventional value is mainly calculated from the US and other developed economies' data. It is likely that other countries, especially developing countries, have a different value of labor income share. By choosing a unique value of α, I try to make my priors as informative as possible. In a standard Cobb-Douglas production function, the value of the labor share can be calculated by dividing the total wage income by the aggregate income. However, this conventional method has been criticized as it tends to systematically underestimate the value of labor share, especially for the developing countries where a large portion of income from self-employment is omitted from statistics of national accounts.

Table 1. Gollin's Estimates of Labor Income Share

Country	Naive	Adj. 1	Adj. 2
Australia	0.504	0.719	0.669
Belarus	0.554	0.514	
Belgium	0.547	0.791	0.743
Bolivia	0.256	0.835	0.627
Botswana	0.302	0.368	0.341
Burundi	0.201	0.914	0.728
Congo	0.372	0.691	0.578
Ecuador	0.213	0.82	0.571
Estonia	0.606	0.574	
Finland	0.575	0.765	0.734
France	0.525	0.764	0.717
Hungary	0.585	0.802	0.772
India	0.691	0.838	0.828
Italy	0.451	0.804	0.717
Ivory Coast	0.287	0.809	0.69
Jamaica	0.427	0.616	0.566
Japan	0.564	0.727	0.692
Korea	0.472	0.768	0.697
Latvia	0.55	0.471	
Malta	0.434	0.714	0.632
Mauritius	0.392	0.767	0.668
Netherlands	0.532	0.721	0.68
Norway	0.519	0.678	0.643
Philippines	0.353	0.8	0.661
Portugal	0.448	0.825	0.748
Re'union	0.595	0.832	0.799
Sweden	0.613	0.8	0.774
Ukraine	0.797	0.762	
UK	0.574	0.815	0.782
US	0.604	0.773	0.743
Vietnam	0.835	0.802	

Methods to correct for the underestimation have been proposed by Gollin (2002). By incorporating the information of indirect taxes and OSPUE (Operating Surplus of Private Unincorporated Enterprises) of each country's national income, he claims that the correct labor income share should be between .65 and .80 for most countries. For example, Table 1 shows his estimates of labor income shares of various countries. The column of naive measure shows the results calculated with conventional methods, and the columns of

Adjustment 1 and Adjustment 2 show the results with corrections for the underestimation.

Table 2. Naive Measures and Adjustment Ratio (Developed Countries)

Country	adj1/naive	=adj2/naive
Australia	1.43	1.33
Belgium	1.45	1.36
Finland	1.33	1.28
France	1.46	1.37
Italy	1.78	1.59
Japan	1.29	1.23
Netherlands	1.36	1.28
Norway	1.31	1.24
Portugal	1.84	1.67
Sweden	1.31	1.26
UK	1.42	1.36
US	1.28	1.23
mean	1.44	1.35
median	1.39	1.30
std	0.18	0.14

According to Gollin (2002), the two adjustments generate similar results, and are both reasonable. In Table 2, I list the ratio of the two adjustments and the naive measure for developed countries. It shows that the ratio is stable across all the developed countries. I also calculate the ratio of corrected values and the naive measure for developing countries. Table 3 shows the ratios for developing countries excluding four outliers (Bolivia, Burundi, Ecuador, and Ivory Coast). The range of the ratio is larger than the range of the developed countries, but it is still relatively stable.

Table 3. Naive Measures and Adjustment Ratio (Developing Countries)

Country	adj1/naive	aj2/naive
Belarus	1.33	1.23
Bolivia	3.26	2.45
Botswana	1.22	1.13
Burundi	4.55	3.62
Congo	1.86	1.55
Ecuador	3.85	2.68
Estonia	1.29	1.22
Hungary	1.37	1.32
India	1.21	1.20
Ivory Coast	2.82	2.40
Jamaica	1.44	1.33
Korea	1.63	1.48
Latvia	0.86	
Malta	1.65	1.46
Mauritius	1.96	1.70
Philippines	2.27	1.87
Ukraine	1.04	0.99
Vietnam	1.41	1.35
mean	1.51	1.37
median	1.53	1.46
std	1.00	0.68

In this paper, I follow the method proposed by Gollin (2002) to calculate the value of labor share for each country, and use its value as the mean of their prior distribution. However, for certain country in our sample, the data is limited, and hence it is impossible to directly obtain the value of their labor income share with Gollin's method. So due to the stability of the ratio between the corrected value and the naive value of the labor income share, my strategy is to use the average value of α in their group as their prior mean. Moreover, I assign a much larger standard deviation for their prior distribution, which reflects the lack of information on their labor share. The prior distribution of α for each country is showed in Table 4.

Table 4. Prior Distribution of α (Benchmark & Alternative 2)

Country	Dist.	Mean	S. D.
Argentina	beta	0.68	0.20
Brazil	beta	0.57	0.05
Ecuador	beta	0.85	0.05
Isreal	beta	0.70	0.05
Korea	beta	0.64	0.05
Malaysia	beta	0.68	0.20
Mexico	beta	0.42	0.05
Peru	beta	0.68	0.20
Philippines	beta	0.80	0.05
Slovakia	beta	0.68	0.20
South Africa	beta	0.63	0.05
Thailand	beta	0.68	0.20
Turkey	beta	0.68	0.20
Australia	beta	0.72	0.05
Austria	beta	0.68	0.05
Belgium	beta	0.79	0.05
Canada	beta	0.71	0.05
Denmark	beta	0.75	0.05
Finland	beta	0.77	0.05
Netherlands	beta	0.72	0.05
New Zealand	beta	0.59	0.05
Norway	beta	0.68	0.05
Portugal	beta	0.82	0.05
Spain	beta	0.66	0.05
Sweden	beta	0.80	0.05
Switzerland	beta	0.86	0.05

In the benchmark estimation, I estimate all the parameters model with Bayesian methods with only one exception: the value of the discount factor β is fixed to be 0.98 in consistence with the literature. I list the prior of all the other parameters in Table 5. For the benchmark estimation, it includes the parameters for household's preferences, capital depreciation rate, capital adjustment costs, output growth rate at the steady state, as well as productivity shocks. For the two alternatives, it only includes the parameters for the productivity shocks. The mean of those parameters are mainly drawn from the real business cycle literature. For all the persistence parameter (ρ_g, ρ_z), I set their prior as Beta Distribution with mean 0.6 and standard deviation 0.2. The prior distribution

Table 5. Prior Distribution: other parameters

Parameter	Dist.	Mean	S. D.
	Benchmark		
δ	beta	0.025	0.02
σ	normal	2	0.5
γ	beta	0.36	0.05
μ_g	gamma	1.006	0.002
ϕ	gamma	4	1
ρ_g	beta	0.6	0.2
ρ_z	beta	0.6	0.2
σ_g	inv. gam.	0.01	∞
σ_z	inv. gam.	0.01	∞
	Alternative 1 & 2		
ρ_g	beta	0.6	0.2
ρ_z	beta	0.6	0.2
σ_g	inv. gam.	0.01	∞
σ_z	inv. gam.	0.01	∞

is relatively loose for those parameters so that I do not form a strong belief about the persistence parameters. For all the other parameters, I mainly adopt the commonly used value in the literature or the values used by Aguiar and Gopinath (2007).

Detrending and Log-Linearization

As I incoporate a stochastic trend for the productivity shock into the model, the Bayesian estimation requires to detrend and log-linearize the model in order to obtain a stationary solution. I use lower-case letters to denote the detrended variables, and $\hat{x}$ denotes the log-deviation of x from its steady-state value. Therefore I have $z_t \equiv Z_t/\Gamma_{t-1}$,where $Z_t \equiv (K_t, Y_t, C_t, I_t)'$.

Hence for the measurement equation of output, it should satisfy

$$\Delta \ln(Y_t) = (\hat{y}_t - \hat{y}_{t-1}) + \hat{g}_{t-1} + \mu_g. \tag{I.8}$$

Data

I employ two datasets for my empirical studies. For the Bayesian estimation, I use the same dataset of Aguiar and Gopinath (2007) to maintain compatibility. This dataset contains 26 countries, including 13 developed countries and 13 developing countries[1]. I retrieve $\Delta \ln(Y_t)$,and $\Delta \ln(C_t)$ for each country. Also, to calculate the prior mean of α, I employ the compensation and unemployment data from United Nations.

Empirical Results

Benchmark Estimation

Structural Parameters

[1]The criteria of differentiating developing and developed countries is the same as in Aguiar and Gopinath (2007).

Table 6. Posterior Dist. of σ

Country	Mean	S.D.	90% Conf. Interval
Developing Countries			
Argentina	1.93	0.53	[1.29 , 2.58]
Brazil	1.41	1.11	[0.49 , 2.20]
Ecuador	0.20	0.08	[0.03 , 0.38]
Isreal	1.73	0.62	[0.97 , 2.00]
Korea	2.25	0.45	[1.69 , 2.80]
Malaysia	1.69	0.65	[0.92 , 2.35]
Mexico	2.13	0.47	[1.55 , 2.75]
Peru	1.93	0.53	[1.33 , 2.48]
Philippines	0.96	0.43	[0.45 , 1.50]
Slovakia	2.16	0.78	[1.39 , 2.84]
South Africa	0.51	0.22	[0.11 , 1.08]
Thailand	2.06	0.49	[1.46 , 2.62]
Turkey	2.17	0.49	[1.54 , 2.86]
Mean	1.63		
Developed Countries			
Australia	0.91	0.33	[0.47 , 1.44]
Austria	1.82	0.53	[1.19 , 2.48]
Belgium	1.82	0.47	[1.27 , 2.35]
Canada	2.05	0.47	[1.51 , 2.60]
Denmark	1.76	0.55	[1.08 , 2.46]
Finland	2.07	0.45	[1.54 , 2.60]
Netherlands	1.78	0.54	[1.12 , 2.40]
New Zealand	2.00	0.49	[1.39 , 2.55]
Norway	1.73	0.53	[1.16 , 2.37]
Portugal	1.99	0.47	[1.48 , 2.55]
Spain	1.89	0.48	[1.29 , 2.48]
Sweden	1.88	0.54	[1.20 , 2.60]
Switzerland	1.14	0.35	[0.66 , 1.64]
Mean	1.76		

Parameters in the preference function are mostly identical across all the countries. Table 6 and Table 7 report the estimates of preference parameters for the developing and developed countries. Table 6 shows that the intertemporal rates of substitution for the developing countries and developed countries are of no significant differences. Moreover, the posterior mean of σ is only slightly higher than the prior mean, which confirms the commonly used value of 2 for σ is reasonable for most studies. Similarly, Table 7 shows that the posterior mean of γ of developing countries is very close to the same parameter of

Table 7. Posterior Dist. of γ

Country	Mean	S.D.	90% Conf. Interval
Developing Countries			
Argentina	0.348	0.050	[0.280 , 0.414]
Brazil	0.368	0.058	[0.301 , 0.439]
Ecuador	0.346	0.054	[0.283 , 0.417]
Isreal	0.367	0.053	[0.288 , 0.451]
Korea	0.353	0.049	[0.283 , 0.421]
Malaysia	0.338	0.051	[0.272 , 0.408]
Mexico	0.366	0.050	[0.306 , 0.428]
Peru	0.369	0.051	[0.306 , 0.433]
Philippines	0.373	0.055	[0.304 , 0.446]
Slovakia	0.347	0.061	[0.299 , 0.406]
South Africa	0.268	0.048	[0.202 , 0.334]
Thailand	0.371	0.051	[0.313 , 0.431]
Turkey	0.375	0.051	[0.315 , 0.432]
Mean	0.353		
Developed Countries			
Australia	0.359	0.054	[0.292 , 0.427]
Austria	0.379	0.051	[0.308 , 0.439]
Belgium	0.354	0.050	[0.292 , 0.423]
Canada	0.371	0.049	[0.312 , 0.433]
Denmark	0.348	0.051	[0.282 , 0.417]
Finland	0.368	0.049	[0.311 , 0.430]
Netherlands	0.337	0.051	[0.275 , 0.404]
New Zealand	0.370	0.051	[0.314 , 0.425]
Norway	0.338	0.052	[0.277 , 0.400]
Portugal	0.365	0.050	[0.305 , 0.425]
Spain	0.341	0.049	[0.285 , 0.399]
Sweden	0.365	0.051	[0.294 , 0.442]
Switzerland	0.320	0.049	[0.263 , 0.381]
Mean	0.355		

developed countries.

Table 8. Posterior Dist. of α

	Mean	S.D.	90% Conf. Interval
	Developing Countries		
Argentina	0.71	0.09	[0.59 , 0.84]
Brazil	0.55	0.05	[0.50 , 0.62]
Ecuador	0.78	0.04	[0.72 , 0.83]
Isreal	0.69	0.05	[0.63 , 0.72]
Korea	0.66	0.04	[0.59 , 0.72]
Malaysia	0.56	0.08	[0.45 , 0.65]
Mexico	0.48	0.05	[0.41 , 0.54]
Peru	0.72	0.12	[0.56 , 0.86]
Philippines	0.80	0.05	[0.73 , 0.85]
Slovakia	0.16	0.12	[0.08 , 0.26]
South Africa	0.61	0.05	[0.54 , 0.67]
Thailand	0.77	0.11	[0.56 , 0.93]
Turkey	0.83	0.08	[0.72 , 0.94]
Mean	0.64		
	Developed Countries		
Australia	0.72	0.05	[0.66 , 0.78]
Austria	0.66	0.05	[0.60 , 0.72]
Belgium	0.78	0.05	[0.71 , 0.84]
Canada	0.74	0.05	[0.68 , 0.80]
Denmark	0.73	0.05	[0.67 , 0.80]
Finland	0.78	0.05	[0.73 , 0.84]
Netherlands	0.71	0.05	[0.66 , 0.77]
New Zealand	0.60	0.05	[0.54 , 0.66]
Norway	0.68	0.05	[0.62 , 0.73]
Portugal	0.81	0.05	[0.74 , 0.88]
Spain	0.66	0.05	[0.61 , 0.72]
Sweden	0.77	0.05	[0.70 , 0.84]
Switzerland	0.80	0.05	[0.73 , 0.86]
Mean	0.73		

The labor income share shows moderate diversity among countries. I have two findings of interest according to Table 8. First, we can see that the value of α varies slightly more in developing countries. It ranges from 0.48 to 0.80 for developing countries, and from 0.60 to 0.81 for developed countries. Second, the labor shares in the developing countries are slightly lower in the developing countries. Excluding Slovakia, the mean of α is 0.68 for developing countries, and 0.73 for developed countries. My results are consistent with the statements in Gollin (2002) that most countries' labor shares are in the range of 0.65 and 0.80. However, in contrast to Gollin's claim that developing countries will have similar labor shares with developed countries after the correction, I find four 5 of 12 developing countries in my sample have lower income shares than the lower bound of 0.60. So the fact that "poor" countries usually have lower income shares cannot be merely taken as measurement errors, as Gollin implies. The capital generally depreciates slower in the developed countries than in

Table 9. Posterior Dist. of δ

Country	Mean	S.D.	90% Conf. Interval
	Developing Countries		
Argentina	0.059	0.021	[0.030 , 0.092]
Brazil	0.090	0.027	[0.050 , 0.138]
Ecuador	0.054	0.020	[0.025 , 0.083]
Isreal	0.041	0.023	[0.027 , 0.067]
Korea	0.047	0.017	[0.022 , 0.077]
Malaysia	0.074	0.024	[0.039 , 0.110]
Mexico	0.081	0.021	[0.054 , 0.112]
Peru	0.030	0.017	[0.009 , 0.057]
Philippines	0.036	0.017	[0.007 , 0.077]
Slovakia	0.049	0.032	[0.016 , 0.087]
South Africa	0.108	0.038	[0.065 , 0.159]
Thailand	0.032	0.017	[0.007 , 0.062]
Turkey	0.031	0.015	[0.010 , 0.059]
Mean	0.056		
	Developed Countries		
Australia	0.048	0.021	[0.017 , 0.086]
Austria	0.030	0.016	[0.010 ,0.053]
Belgium	0.033	0.017	[0.009 , 0.065]
Canada	0.036	0.017	[0.009 , 0.067]
Denmark	0.038	0.019	[0.014 , 0.068]
Finland	0.046	0.022	[0.019 , 0.083]
Netherland	0.063	0.025	[0.032 ,0.099]
New Zealand	0.045	0.020	[0.019 , 0.077]
Norway	0.055	0.024	[0.025 , 0.093]
Portugal	0.034	0.017	[0.008 , 0.071]
Spain	0.071	0.026	[0.039 ,0.111]
Sweden	0.041	0.021	[0.014 , 0.083]
Switzerland	0.055	0.027	[0.016 , 0.097]
Mean	0.046		

the developing ones. Table 9 summarizes the capital depreciation rate, δ, for the developing and developed countries. In general, the capital depreciation is faster in the developing countries: the average depreciation rate is 5.6 percent for developing countries, and 4.6 percent for developed countries. Moreover, I find that the capital depreciation rates vary more for the developing countries. For example, Brazil, Mexico, and South Africa have very high capital depreciation rates that are larger than 8 percent, while the developed country with the fastest capital depreciation is Spain, which has a capital depreciation rate of 7.1 percent.

Table 10. Posterior Dist. of ϕ

Country	Mean	S.D.	90% Conf. Interval
Developing Countries			
Argentina	4.84	1.06	[3.58 , 6.10]
Brazil	4.45	1.03	[3.15 , 5.75]
Ecuador	4.45	0.98	[3.26 , 5.78]
Isreal	4.50	1.00	[3.72 , 5.39]
Korea	4.64	1.03	[3.29 , 6.14]
Malaysia	4.60	1.02	[3.26 , 6.05]
Mexico	5.53	1.15	[4.02 , 7.03]
Peru	4.02	0.96	[2.91 , 5.37]
Philippines	4.16	0.99	[2.83 , 5.72]
Slovakia	4.98	1.02	[3.09 , 7.25]
South Africa	3.97	0.98	[2.71 , 5.32]
Thailand	3.95	0.97	[2.70 , 5.19]
Turkey	4.32	1.01	[2.92 , 5.69]
Mean	4.49		
Developed Countries			
Australia	4.10	1.01	[2.97 , 5.40]
Austria	3.80	0.96	[2.65 , 5.11]
Belgium	4.02	0.98	[2.77 , 5.38]
Canada	3.90	1.04	[2.71 , 5.18]
Denmark	4.06	0.97	[2.91 , 5.21]
Finland	4.34	1.02	[3.05 , 5.79]
Netherlands	4.12	0.98	[2.89 , 5.64]
New Zealand	4.28	1.03	[3.13 , 5.70]
Norway	4.33	1.00	[3.12 , 5.61]
Portugal	4.13	0.98	[2.89 , 5.50]
Spain	4.46	1.06	[3.33 , 5.78]
Sweden	3.88	0.95	[2.67 , 5.46]
Switzerland	3.49	0.96	[2.39 , 4.69]
Mean	4.07		

Besides faster capital depreciation, developing countries also suffer from larger capital adjustment costs. Table 10 represents our estimation result of parameter ϕ which controls the capital adjustment cost. According to the table, the capital adjustment costs are 10 percent higher in the developing countries than in the developed ones: the average value of theta is 4.49 for developing countries, and 4.07 for developed countries. It is worth noting that this finding is in contrast with AG, where the authors argued that the capital adjustment costs for Mexico is not significantly higher than Canada.

TFP Growth

Table 11. Posterior Dist. of μ_g

Country	Mean	S.D.	90% Conf. Interval
	Developing Countries		
Argentina	1.0043	0.0018	[1.0020 , 1.0064]
Brazil	1.0067	0.0019	[1.0040 , 1.0091]
Ecuador	1.0057	0.0018	[1.0038 , 1.0077]
Isreal	1.0078	0.0016	[1.0067 , 1.0094]
Korea	1.0087	0.0015	[1.0068 , 1.0104]
Malaysia	1.0058	0.0018	[1.0034 ,1.0081]
Mexico	1.0065	0.0015	[1.0047 , 1.0082]
Peru	1.0055	0.0018	[1.0030 , 1.0079]
Philippines	1.0060	0.0013	[1.0041 , 1.0079]
Slovakia	1.0062	0.0018	[1.0037 , 1.0084]
South Africa	1.0071	0.0013	[1.0053 , 1.0088]
Thailand	1.0069	0.0018	[1.0047 , 1.0092]
Turkey	1.0059	0.0018	[1.0038 , 1.0083]
Mean	1.0064		
	Developed Countries		
Australia	1.0076	0.0006	[1.0067 , 1.0084]
Austria	1.0071	0.0008	[1.0060 , 1.0082]
Belgium	1.0043	0.0006	[1.0036 , 1.0051]
Canada	1.0064	0.0008	[1.0054 , 1.0074]
Denmark	1.0034	0.0013	[1.0016 , 1.0051]
Finland	1.0059	0.0011	[1.0046 , 1.0072]
Netherlands	1.0038	0.0009	[1.0027 , 1.0050]
New Zealand	1.0058	0.0012	[1.0043 , 1.0072]
Norway	1.0055	0.0012	[1.0038 , 1.0071]
Portugal	1.0073	0.0010	[1.0062 , 1.0085]
Spain	1.0054	0.0008	[1.0044 , 1.0064]
Sweden	1.0040	0.0013	[1.0023 , 1.0054]
Switzerland	1.0031	0.0003	[1.0026 , 1.0036]
Mean	1.0054		

The long-run economic growth rate of developed countries is higher growth rate than of developing countries, but the gap is generally small. Table 11 shows my estimates of μ_g for the developing countries and developed countries. The deterministic growth rate for the developing countries is only slightly lower than the developed countries. This result also confirms the findings in AG, where the authors estimated the deterministic growth rate for Canada and Mexico.

Table 12. Posterior Dist. of ρ_g

Country	Mean	S.D.	90% Conf. Interval
Developing Countries			
Argentina	0.137	0.059	[0.060 , 0.215]
Brazil	0.294	0.157	[0.157 , 0.435]
Ecuador	0.052	0.020	[0.021 , 0.090]
Isreal	0.676	0.107	[0.186 , 0.936]
Korea	0.279	0.058	[0.197 , 0.356]
Malaysia	0.380	0.099	[0.241 , 0.531]
Mexico	0.150	0.058	[0.082 , 0.224]
Peru	0.149	0.048	[0.076 , 0.232]
Philippines	0.334	0.126	[0.214 , 0.449]
Slovakia	0.877	0.163	[0.698 , 0.969]
South Africa	0.075	0.029	[0.035 , 0.123]
Thailand	0.311	0.084	[0.172 , 0.453]
Turkey	0.135	0.043	[0.083 , 0.187]
Mean	0.296		
Developed Countries			
Australia	0.229	0.083	[0.126 , 0.344]
Austria	0.398	0.069	[0.304 , 0.501]
Belgium	0.223	0.086	[0.126 , 0.330]
Canada	0.269	0.062	[0.185 , 0.356]
Denmark	0.492	0.115	[0.325 , 0.668]
Finland	0.472	0.093	[0.363 , 0.591]
Netherlands	0.446	0.128	[0.307 , 0.591]
New Zealand	0.440	0.173	[0.270 , 0.604]
Norway	0.630	0.178	[0.441 , 0.800]
Portugal	0.383	0.119	[0.243 , 0.539]
Spain	0.380	0.092	[0.281 , 0.502]
Sweden	0.347	0.077	[0.136 , 0.773]
Switzerland	0.217	0.125	[0.072 , 0.379]
Mean	0.379		

Table 13. Posterior Dist. of σ_g

Country	Mean	S.D.	90% Conf. Interval
	Developing Countries		
Argentina	0.030	0.004	[0.024 , 0.036]
Brazil	0.047	0.006	[0.039 , 0.054]
Ecuador	0.031	0.003	[0.026 , 0.036]
Isreal	0.010	0.002	[0.002 , 0.023]
Korea	0.019	0.002	[0.016 , 0.022]
Malaysia	0.030	0.004	[0.022 , 0.037]
Mexico	0.023	0.003	[0.019 , 0.027]
Peru	0.040	0.005	[0.031 , 0.048]
Philippines	0.013	0.002	[0.011 , 0.016]
Slovakia	0.015	0.004	[0.010 , 0.024]
South Africa	0.017	0.002	[0.014 , 0.020]
Thailand	0.020	0.003	[0.015 , 0.026]
Turkey	0.032	0.003	[0.027 , 0.036]
Mean	0.025		
	Developed Countries		
Australia	0.005	0.001	[0.005 , 0.006]
Austria	0.006	0.001	[0.005 , 0.007]
Belgium	0.005	0.001	[0.004 , 0.006]
Canada	0.006	0.001	[0.005 , 0.008]
Denmark	0.007	0.002	[0.005 , 0.010]
Finland	0.007	0.001	[0.005 , 0.009]
Netherlands	0.006	0.001	[0.004 , 0.008]
New Zealand	0.008	0.003	[0.005 , 0.011]
Norway	0.006	0.002	[0.003 , 0.009]
Portugal	0.006	0.001	[0.005 , 0.007]
Spain	0.006	0.001	[0.005 , 0.007]
Sweden	0.011	0.002	[0.003 , 0.015]
Switzerland	0.003	0.000	[0.002 , 0.003]
Mean	0.006		

The permanent productivity shocks in developing countries are much more volatile than the permanent productivity shocks in the developed countries. Table 12 and Table 13 report the persistence and volatility of the permanent productivity process for the developing and developed countries. In average, the standard deviation of the innovation term σ_g is 0.025 for developing countries, and only 0.006 for developed countries. This is consistent with our intuition that the developing countries are generally facing more permanent productivity shocks, such as the introduction of advanced technologies, trade liberalization, and political turmoil.

Table 14. Posterior Dist. of ρ_z

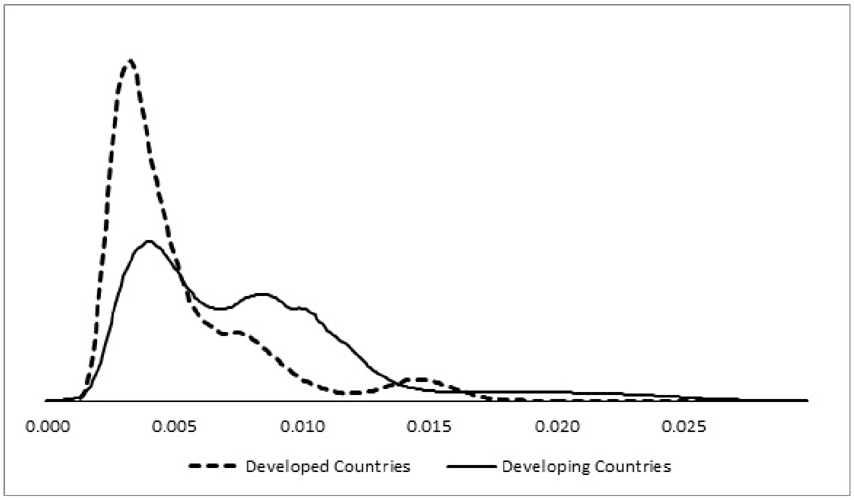
Country	Mean	S.D.	90% Conf. Interval
Developing Countries			
Argentina	0.825	0.062	[0.731 , 0.904]
Brazil	0.676	0.117	[0.519 , 0.817]
Ecuador	0.752	0.083	[0.634 , 0.861]
Isreal	0.944	0.042	[0.852 , 0.993]
Korea	0.901	0.031	[0.856 , 0.939]
Malaysia	0.831	0.071	[0.741 , 0.910]
Mexico	0.890	0.029	[0.858 , 0.922]
Peru	0.827	0.074	[0.730 , 0.932]
Philippines	0.902	0.037	[0.858 , 0.943]
Slovakia	0.854	0.075	[0.785 , 0.948]
South Africa	0.944	0.013	[0.926 , 0.960]
Thailand	0.824	0.075	[0.738 , 0.908]
Turkey	0.778	0.081	[0.676 , 0.869]
Mean	0.842		
Developed Countries			
Australia	0.877	0.028	[0.842 , 0.911]
Austria	0.896	0.046	[0.845 , 0.946]
Belgium	0.855	0.038	[0.809 , 0.900]
Canada	0.923	0.020	[0.899 , 0.945]
Denmark	0.902	0.037	[0.840 , 0.954]
Finland	0.915	0.021	[0.886 , 0.945]
Netherlands	0.939	0.014	[0.914 , 0.958]
New Zealand	0.872	0.054	[0.809 , 0.929]
Norway	0.934	0.017	[0.909 , 0.957]
Portugal	0.862	0.053	[0.802 , 0.923]
Spain	0.921	0.018	[0.894 , 0.943]
Sweden	0.900	0.038	[0.813 , 0.983]
Switzerland	0.893	0.023	[0.866 , 0.922]
Mean	0.899		

Table 15. Posterior Dist. of σ_z

Country	Mean	S.D.	90% Conf. Interval
	Developing Countries		
Argentina	0.012	0.002	[0.010 , 0.015]
Brazil	0.014	0.003	[0.010 , 0.017]
Ecuador	0.006	0.001	[0.004 , 0.008]
Isreal	0.015	0.002	[0.011 , 0.019]
Korea	0.010	0.001	[0.009 , 0.012]
Malaysia	0.012	0.002	[0.009 , 0.016]
Mexico	0.011	0.001	[0.010 , 0.013]
Peru	0.015	0.002	[0.011 , 0.022]
Philippines	0.010	0.002	[0.008 , 0.011]
Slovakia	0.011	0.002	[0.010 , 0.012]
South Africa	0.006	0.001	[0.005 , 0.007]
Thailand	0.012	0.002	[0.009 , 0.015]
Turkey	0.012	0.002	[0.009 , 0.014]
Mean	0.011		
	Developed Countries		
Australia	0.005	0.001	[0.005 , 0.006]
Austria	0.003	0.000	[0.003 , 0.004]
Belgium	0.004	0.001	[0.004 , 0.005]
Canada	0.005	0.001	[0.004 , 0.005]
Denmark	0.007	0.001	[0.005 , 0.008]
Finland	0.009	0.001	[0.007 , 0.010]
Netherlands	0.007	0.001	[0.006 , 0.007]
New Zealand	0.008	0.001	[0.007 , 0.010]
Norway	0.011	0.001	[0.010 , 0.013]
Portugal	0.006	0.001	[0.005 , 0.007]
Spain	0.005	0.001	[0.005 , 0.006]
Sweden	0.009	0.001	[0.007 , 0.012]
Switzerland	0.003	0.000	[0.002 , 0.003]
Mean	0.006		

Moreover, the transitory shocks in the developing countries are more volatile than in the developed countries as well. Table 14 and Table 15 show the persistence and volatility of transitory productivity process for the developing countries and the developed countries. According to the tables, the average value of the standard deviation of the innovation term σ_z is 0.011 for developing countries, and 0.006 for developed countries. Our result is contrary to AG, where the authors found the volatility of the transitory shocks in the developing

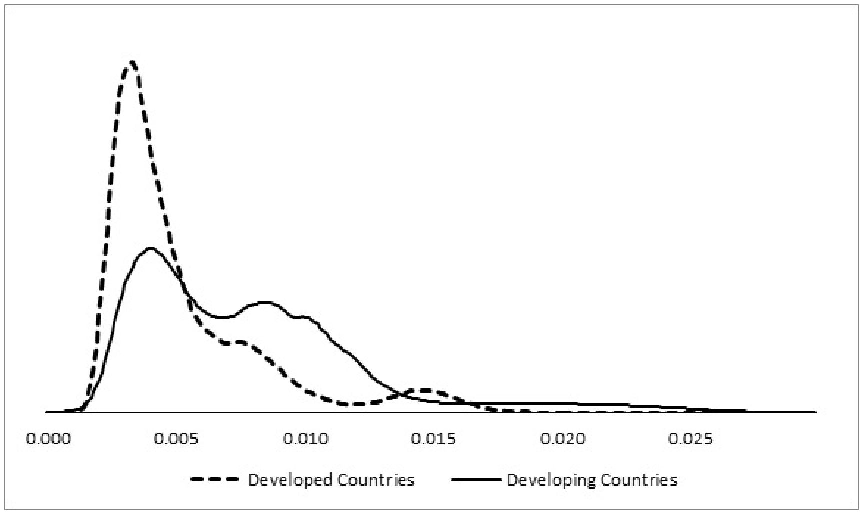
Figure 1. Posterior Distribution of Permanent Shock Volatility



countries are lower than in the developed countries. Our results are more sensible, as the economy of developed countries are generally more robust to transitory shocks, especially at the sectoral level.

I also graphically show the difference of the volatility of the permanent and transitory shocks between developed countries and developing countries in Figure 1 and Figure 2. In Figure 1, I aggregate the posterior distributions of σ_g, which captures the volatility of the permanent part of the productivity, for both developing and developed countries. I find that this value has a tight distribution mostly below 0.005 for developed countries. On the other hand, the value of σ_g for the developing countries are much more diverse, and reaches as high as 0.025. Contrary to the permanent shock, Figure 2 shows that the difference between the distribution of σ_z is relatively small for developed countries and developing countries. Although the distribution of σ_z for emerging countries still more diverse, the mode and the shape of the two distributions are close.

Figure 2. Posterior Distribution of Transitory Shock Volatility



Alternative Estimations and Variance Decomposition

Table 16. Posterior Dist. of ρ_g in Three Estimations

	Benchmark		Alt. 1		Alt. 2	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
Argentina	0.14	0.06	0.15	0.06	0.15	0.06
Brazil	0.29	0.16	0.93	0.07	0.59	0.06
Ecuador	0.05	0.02	0.95	0.09	0.49	0.08
Isreal	0.68	0.11	0.97	0.11	0.52	0.09
Korea	0.28	0.06	0.26	0.04	0.26	0.05
Malaysia	0.38	0.10	0.42	0.06	0.42	0.06
Mexico	0.15	0.06	0.14	0.04	0.15	0.05
Peru	0.15	0.05	0.43	0.04	0.43	0.04
Philippines	0.33	0.13	0.53	0.10	0.45	0.07
Slovakia	0.88	0.16	0.86	0.11	0.81	0.14
South Africa	0.07	0.03	0.30	0.05	0.28	0.05
Thailand	0.31	0.08	0.29	0.07	0.29	0.07
Turkey	0.14	0.04	0.12	0.04	0.11	0.04
Mean	0.30		0.49		0.38	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
Australia	0.23	0.08	0.41	0.12	0.38	0.11
Austria	0.40	0.07	0.57	0.18	0.38	0.05
Belgium	0.22	0.09	0.30	0.10	0.26	0.08
Canada	0.27	0.06	0.26	0.04	0.26	0.06
Denmark	0.49	0.11	0.56	0.11	0.53	0.09
Finland	0.47	0.09	0.45	0.08	0.47	0.08
Netherlands	0.45	0.13	0.97	0.10	0.49	0.09
New Zealand	0.44	0.17	0.40	0.09	0.42	0.18
Norway	0.63	0.18	0.69	0.13	0.70	0.12
Portugal	0.38	0.12	0.59	0.11	0.38	0.10
Spain	0.38	0.09	0.39	0.07	0.40	0.08
Sweden	0.35	0.08	0.62	0.08	0.32	0.06
Switzerland	0.22	0.12	0.94	0.02	0.39	0.13
Mean	0.38		0.55		0.41	

The results of my alternative estimations show that ignoring the heterogeneity of the structural parameters would lead to biased estimates of the shock parameters. I compare the results from the benchmark estimation and the two alternatives in Table 16 through Table 19. They show that the largest bias occurs in the estimation of ρ_g. Both two alternatives tend to overestimate the persistence g_t, especially when we fix the value of α in the first alternative estimation. After adding α into the second alternative estimation, the bias is significantly reduced. Yet the estimate of ρ_g is still higher than in the benchmark

Table 17. Posterior Dist. of σ_g in Three Estimations

	Benchmark		Alt. 1		Alt. 2	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
Argentina	0.030	0.004	0.030	0.004	0.030	0.004
Brazil	0.047	0.006	0.047	0.006	0.028	0.006
Ecuador	0.031	0.003	0.014	0.006	0.023	0.005
Isreal	0.010	0.002	0.010	0.004	0.016	0.003
Korea	0.019	0.002	0.020	0.002	0.020	0.002
Malaysia	0.030	0.004	0.029	0.005	0.029	0.005
Mexico	0.023	0.003	0.020	0.002	0.024	0.003
Peru	0.040	0.005	0.025	0.005	0.025	0.005
Philippines	0.013	0.002	0.012	0.002	0.013	0.002
Slovakia	0.015	0.004	0.014	0.004	0.008	0.005
South Africa	0.017	0.002	0.020	0.003	0.021	0.003
Thailand	0.020	0.003	0.020	0.003	0.020	0.003
Turkey	0.032	0.003	0.031	0.003	0.034	0.003
Mean	0.025		0.022		0.022	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
Australia	0.005	0.001	0.005	0.001	0.005	0.001
Austria	0.006	0.001	0.007	0.002	0.006	0.001
Belgium	0.005	0.001	0.005	0.001	0.005	0.001
Canada	0.006	0.001	0.006	0.001	0.006	0.001
Denmark	0.007	0.002	0.007	0.002	0.007	0.001
Finland	0.007	0.001	0.007	0.001	0.007	0.001
Netherlands	0.006	0.001	0.004	0.001	0.006	0.001
New Zealand	0.008	0.003	0.008	0.001	0.008	0.003
Norway	0.006	0.002	0.005	0.002	0.005	0.002
Portugal	0.006	0.001	0.007	0.001	0.006	0.001
Spain	0.006	0.001	0.006	0.001	0.006	0.001
Sweden	0.011	0.002	0.007	0.001	0.011	0.002
Switzerland	0.003	0.000	0.004	0.001	0.003	0.001
Mean	0.006		0.006		0.006	

estimation. Interestingly, despite the estimates of ρ_g, the estimates of the other three parameters ρ_z, σ_g, σ_z, remain very close under the three different settings.

As I have obtained the persistence and volatility of the permanent and transitory shocks for each country, I am able to calculate the proportion of the permanent shock in the total productivity shock. Specifically, I have:

Table 18. Posterior Dist. of ρ_z in Three Estimations

	Benchmark		Alt. 1		Alt. 2	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
Argentina	0.83	0.06	0.83	0.06	0.83	0.06
Brazil	0.68	0.12	0.79	0.12	0.86	0.12
Ecuador	0.75	0.08	0.95	0.06	0.84	0.07
Isreal	0.94	0.04	0.80	0.03	0.91	0.03
Korea	0.90	0.03	0.90	0.03	0.90	0.03
Malaysia	0.83	0.07	0.83	0.06	0.83	0.06
Mexico	0.89	0.03	0.88	0.03	0.89	0.03
Peru	0.83	0.07	0.92	0.06	0.92	0.06
Philippines	0.90	0.04	0.90	0.03	0.90	0.03
Slovakia	0.85	0.08	0.88	0.08	0.96	0.08
South Africa	0.94	0.01	0.91	0.03	0.91	0.02
Thailand	0.82	0.08	0.83	0.07	0.83	0.07
Turkey	0.78	0.08	0.78	0.08	0.80	0.09
Mean	0.84		0.86		0.87	

	Mean	S. D.	Mean	S. D.	Mean	S. D.
Australia	0.88	0.03	0.85	0.03	0.86	0.03
Austria	0.90	0.05	0.88	0.08	0.91	0.03
Belgium	0.86	0.04	0.87	0.03	0.88	0.03
Canada	0.92	0.02	0.92	0.02	0.93	0.02
Denmark	0.90	0.04	0.91	0.03	0.92	0.03
Finland	0.92	0.02	0.92	0.02	0.92	0.02
Netherlands	0.94	0.01	0.92	0.01	0.94	0.01
New Zealand	0.87	0.05	0.85	0.08	0.87	0.05
Norway	0.93	0.02	0.94	0.02	0.94	0.02
Portugal	0.86	0.05	0.85	0.05	0.87	0.05
Spain	0.92	0.02	0.92	0.02	0.92	0.02
Sweden	0.90	0.04	0.93	0.02	0.91	0.03
Switzerland	0.89	0.02	0.90	0.02	0.90	0.02
Mean	0.90		0.90		0.90	

$$\frac{\sigma^2_{\Delta\tau}}{\sigma^2_{\Delta sr}} = \frac{\alpha^2\sigma_g^2/(1-\rho_g)^2}{[2/(1+\rho_z)]\sigma_z^2 + \alpha^2\sigma_g^2/(1-\rho_g)^2}, \tag{I.9}$$

where $\sigma^2_{\Delta\tau}$ is the variance of the permanent shock and $\sigma^2_{\Delta sr}$ is the variance of the Solow residuals.

Table 19. Posterior Dist. of σ_z in Three Estimations

	Benchmark		Alt. 1		Alt. 2	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
Argentina	0.012	0.002	0.013	0.002	0.013	0.002
Brazil	0.014	0.003	0.017	0.002	0.021	0.002
Ecuador	0.006	0.001	0.018	0.002	0.017	0.002
Isreal	0.015	0.002	0.017	0.002	0.016	0.001
Korea	0.010	0.001	0.010	0.001	0.010	0.001
Malaysia	0.012	0.002	0.013	0.001	0.013	0.001
Mexico	0.011	0.001	0.008	0.001	0.011	0.001
Peru	0.015	0.002	0.024	0.002	0.024	0.002
Philippines	0.010	0.002	0.012	0.001	0.011	0.001
Slovakia	0.011	0.002	0.011	0.002	0.013	0.002
South Africa	0.006	0.001	0.008	0.001	0.008	0.001
Thailand	0.012	0.002	0.011	0.002	0.011	0.002
Turkey	0.012	0.002	0.012	0.001	0.014	0.002
Mean	0.011		0.013		0.014	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
Australia	0.005	0.001	0.006	0.001	0.006	0.000
Austria	0.003	0.000	0.004	0.000	0.003	0.000
Belgium	0.004	0.001	0.005	0.001	0.005	0.000
Canada	0.005	0.001	0.004	0.000	0.005	0.001
Denmark	0.007	0.001	0.007	0.001	0.007	0.001
Finland	0.009	0.001	0.008	0.001	0.008	0.001
Netherlands	0.007	0.001	0.008	0.001	0.007	0.001
New Zealand	0.008	0.001	0.008	0.001	0.008	0.001
Norway	0.011	0.001	0.011	0.001	0.012	0.001
Portugal	0.006	0.001	0.008	0.001	0.006	0.001
Spain	0.005	0.001	0.005	0.001	0.006	0.000
Sweden	0.009	0.001	0.012	0.001	0.010	0.001
Switzerland	0.003	0.000	0.005	0.000	0.004	0.000
Mean	0.006		0.007		0.007	

The results of variance decomposition in Table 20 indicate the relative importance of the permanent shock in the aggregate productivity shock for developing and developed countries. It shows that the volatility of the permanent shock accounts for a much larger portion of the productivity shock in developing countries than in the developed countries. In my benchmark estimation, the permanent shocks account for 77 percent of TFP fluctuation for developing countries, and 58 percent for developed countries. This results is generally in line with Aguiar and Gopinath (2007) that ratio is 0.96 for Mexico and 0.37 for Canada.

Table 20. Variance Ratios: Proportion of the Permanent Productivity Shocks

	Benchmark		Alt. 1		Alt. 2	
	Mean	90% C. I.	Mean	90% C. I.	Mean	90% C. I.
Argentina	0.77	[0.64 , 0.89]	0.75	[0.64 , 0.84]	0.78	[0.65 , 0.88]
Brazil	0.84	[0.72 , 0.94]	0.89	[0.84 , 0.94]	0.69	[0.21 , 0.97]
Ecuador	0.94	[0.88 , 0.97]	0.77	[0.63 , 0.90]	0.65	[0.07 , 0.99]
Isreal	0.57	[0.02 , 0.99]	0.56	[0.03 , 0.99]	0.58	[0.09 , 0.96]
Korea	0.72	[0.61 , 0.82]	0.75	[0.66 , 0.83]	0.73	[0.62 , 0.82]
Malaysia	0.78	[0.60 , 0.92]	0.84	[0.76 , 0.91]	0.82	[0.70 , 0.92]
Mexico	0.55	[0.41 , 0.68]	0.76	[0.69 , 0.82]	0.65	[0.54 , 0.76]
Peru	0.79	[0.64 , 0.92]	0.76	[0.63 , 0.86]	0.54	[0.03 , 0.98]
Philippines	0.71	[0.56 , 0.84]	0.64	[0.45 , 0.79]	0.71	[0.57 , 0.82]
Slovakia	0.67	[0.14 , 0.99]	0.63	[0.05 , 0.99]	0.61	[0.07 , 0.99]
South Africa	0.76	[0.66 , 0.85]	0.79	[0.70 , 0.87]	0.79	[0.70 , 0.87]
Thailand	0.75	[0.54 , 0.90]	0.68	[0.52 , 0.82]	0.75	[0.58 , 0.88]
Turkey	0.85	[0.77 , 0.92]	0.75	[0.66 , 0.82]	0.72	[0.58 , 0.84]
Mean	0.75		0.73		0.69	
Australia	0.77	[0.32 , 0.61]	0.44	[0.27 , 0.61]	0.46	[0.30 , 0.64]
Austria	0.80	[0.68 , 0.90]	0.79	[0.70 , 0.86]	0.79	[0.68 , 0.88]
Belgium	0.57	[0.43 , 0.71]	0.45	[0.32 , 0.59]	0.52	[0.39 , 0.65]
Canada	0.64	[0.51 , 0.77]	0.56	[0.43 , 0.67]	0.60	[0.46 , 0.71]
Denmark	0.69	[0.45 , 0.89]	0.64	[0.43 , 0.84]	0.69	[0.49 , 0.84]
Finland	0.58	[0.40 , 0.75]	0.49	[0.31 , 0.67]	0.57	[0.41 , 0.73]
Netherlands	0.56	[0.34 , 0.77]	0.55	[0.36 , 0.73]	0.56	[0.39 , 0.73]
New Zealand	0.50	[0.25 , 0.75]	0.54	[0.35 , 0.73]	0.47	[0.24 , 0.70]
Norway	0.48	[0.16 , 0.81]	0.50	[0.21 , 0.77]	0.51	[0.21 , 0.81]
Portugal	0.59	[0.39 , 0.78]	0.48	[0.29 , 0.69]	0.57	[0.40 , 0.74]
Spain	0.56	[0.40 , 0.71]	0.56	[0.42 , 0.69]	0.56	[0.41 , 0.71]
Sweden	0.60	[0.15 , 0.94]	0.54	[0.20 , 0.84]	0.59	[0.26 , 0.84]
Switzerland	0.49	[0.32 , 0.66]	0.45	[0.24 , 0.66]	0.54	[0.35 , 0.71]
Mean	0.60		0.54		0.57	

Comparing my results to theirs, my ratios are lower for developing countries, and higher for developed countries. It is because that developing countries generally have lower labor shares. Therefore, by correcting for the value of labor shares, I get less striking differences across the two country groups. But the conclusion still holds qualitatively.

I also graphically represent the distribution of this ratio in Figure 3 and Figure 4. Two findings are worth mentioning. First, ratios for developed and developing countries have very different distributions: the ratio for developing countries has a very heavy-tail distribution towards 1, while the distribution for developed countries is closer to normal distribution. Second, the ratio distribution across estimations varies more in Figure 3 than in Figure 4. It means that ignoring the heterogeneity of parameters matters more for developing countries. This is natural because the labor shares are more diversified for the developing countries, according to my previous estimation.

Concluding Remarks

In this paper I use Bayesian methods to fully estimate the small open economy model augmented with both permanent and transitory productivity shocks for a large group of countries. First, I find that structural parameters are moderately heterogeneous across countries. Ignoring such heterogeneity will introduce biases into the estimation of productivity shocks, especially for developing countries. Second, both permanent TFP shocks and transitory TFP shocks are more volatile in the developing countries than in the developed countries. Variance decomposition shows that the permanent TFP shocks in the developing countries account for 20 percent more total productivity fluctuation than in the developed countries. This gap is smaller than the result in Aguiar and Gopinath (2007) as I control for the heterogeneity of labor shares. But our results are qualitatively consistent. Third, I find that capital depreciation is faster in developing countries than in developed countries. Fourth, the capital adjustment cost is higher in developing countries, which may further depress the investment in those countries, and thus reduce consumption smoothing behaviors of the households.

CHAPTER II

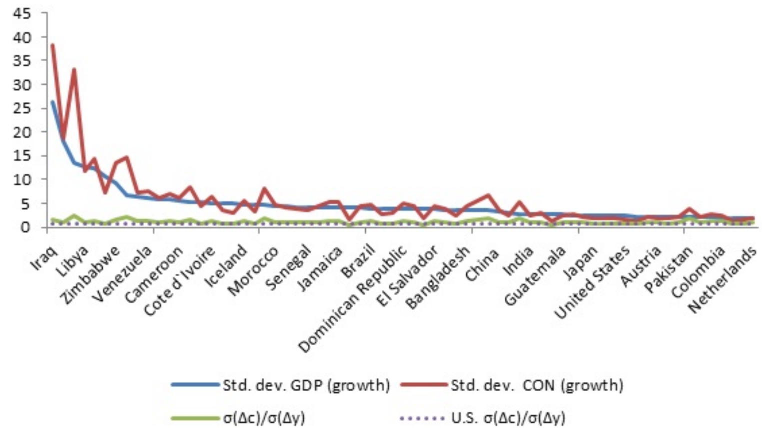
Comparing General and Partial Equilibrium Approaches to the Study of Real Business Cycles

Introduction

The variability of business cycles differs dramatically across the nations of the world. Figure 1 presents the standard deviation of income and consumption growth across the broadest possible sample: the 161 nations found in the PWT tables data over the period 1971 to 2005. Countries are ordered from the most to least volatile based on the standard deviation of their real GDP growth. They range in variability from an astounding 27.5% in Lebanon to a mere 1.88% in the Netherlands; the median country is Samoa (5.16%). Perhaps not surprisingly, the United States has one of the least volatile business cycles, ranking 149th. OECD nations occupy 16 of the 20 least volatile positions in the ranking. The often-cited business cycle fact that the ratio of the standard deviation of consumption growth relative to output growth is much less than one in the United States is a feat achieved by only 11 of the 161 nations in the PWT (the line at the bottom of the figure presents this ratio by country along with the U.S. benchmark value of 0.69). The median volatility ratio is 1.18. Nations with more GDP volatility tend to have more consumption volatility: the correlation of output and consumption volatility across nations is 0.76. An important goal for business cycle research is to explain this business cycle heterogeneity.

One possible approach is to consider the economic interactions of countries in general equilibrium. This was the approach originally taken by Backus, Kehoe and Kydland (1992) and Baxter and Crucini (1993). Another possible approach is to consider each

Figure 1. International business cycles



country in isolate as a small open economy in a partial equilibrium setting. This was the approach originally taken by Mendoza (1991). We refer to these approaches as the dynamic stochastic general equilibrium (DSGE) approach and the dynamic stochastic partial equilibrium (DSPE) approach, respectively. Many papers have been written following one of these approaches, but there has been virtually no discussion of the trade-offs between the two. The general equilibrium approach has the advantage of determining both quantities and prices. However the challenge in matching both dimensions is often unmet leaving the models open to criticism and mistrust (see, for example, the six puzzles paper of Obstfeld and Rogoff (2000)). The partial equilibrium approach appears to enjoy more empirical success, but at the expense of not identifying the underlying foreign shocks. Put differently, the treatment of an endogenous variable such as the world interest rate as an exogenous stochastic process is a reduced form and thus subject to the Lucas (1972) critique. The two approaches also typically embody different underlying risk sharing assumptions. The partial equilibrium model assumes individuals pool risks within countries, but not across them, while most general equilibrium models start from the premise that idiosyncratic risks are fully pooled everywhere. It seems important, then, to consider the general implications of these modeling choices for the risk sharing mechanisms that they imply.[1]

The goal of this paper is to compare and contrast the general equilibrium and partial equilibrium approaches to modeling international business cycle transmission in the context of the business cycle patterns found in Figure 1. The model of Baxter and Crucini (1995) is used for the DSGE model because as size of one of the two countries converges toward zero, it collapses to the DSPE model of Mendoza (1991) when the exogenous interest rate process is correctly specified. For tractability we restrict our attention to home and foreign total factor productivity (TFP) shocks as the driving variables. In the general equilibrium model these two exogenous variables determine the evolution of the world interest rate. In the partial equilibrium model the interest rate is modeled as an autoregressive process as Mendoza originally did. We then conduct a number of variance decompositions of output and consumption growth, by country, into the exogenous sources. Comparing these across the general and partial equilibrium approach reveals the important trade-offs that exist across the two modeling approaches.

Recognizing the importance of permanent and transitory shocks emphasized in the emerging market context by Aguiar and Gopinath (2007) a rich stochastic process for productivity is developed. Productivity in each country is a combination of permanent and transitory (but persistent) components unique to the nation and shared with the large industrialized group.

Apart from the fact that agents trade only in commodities and one-period non-contingent bonds, financial frictions are absent from the analysis. Adding financial frictions

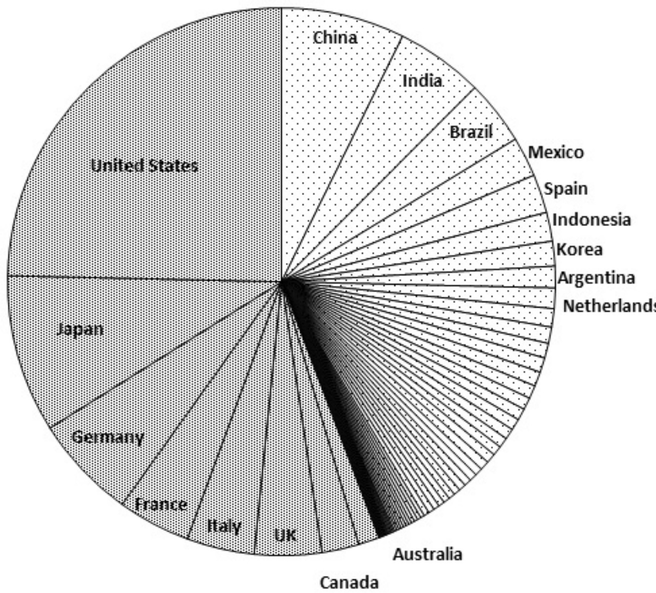
[1] To emphasize this point, reading the international business cycle literature one gets the impression that autarky is a better approach to modeling large open economies than is the DSGE approach (see Heathcote and Perri (2002)) while the small open economy approach with an elastic supply of international credit better matches the business cycles of the typical small open economy. Ironically large open economies seem open enough to drive small open economy business cycles, leading to a modeling quandry of sorts.

such as an interest rate spread that varies with the movements in national debt and productivity as in Uribe and Yue (2006), is an obvious and fruitful next step to the exercises conducted here.[2] These frictions are ignored here to sharpen the focus on the role of home and foreign productivity in determining a single world real interest rate. Gauging the trade-offs of general equilibrium and partial equilibrium approaches in the more sophisticated setting of heterogenous interest rates is beyond the scope of this paper.

Turning to the details and beginning with the general equilibrium approach, the strategy used to exploit a tractable two-country model in the context of an N-country empirical investigation is to fix a large region and rotate each small open economy through the simulations keeping the parameters of the stochastic TFP process of the large region fixed. The large region is an aggregate of the G-7 plus Australia, leaving 60 small open economies to pair with this single large region at each iteration. Each small open economy is assumed to have a country-specific component to their productivity process, which combined with their relative economic sizes makes their business cycles heterogeneous relative to each another. Figure 2 shows that the sum of the GDP of the G-8 countries is larger than the aggregate GDP of the rest 60 countries. Since the large region has a disproportionate influence over the world interest rate the simulation method is designed to approximate the quantitative implications of an N-country general equilibrium approach without the exploding the state-space of the model. We calibrate the parameters for each country pair so that the second moments and correlation coefficients of aggregate variables generated by the model match their counterparts in the data. Next, each country is modelled as a small open economy using the DSPE approach, again allowing for both permanent and transitory components in home and foreign TFP, and now with an exogenous world interest

[2]See also, Garcia-Cicco, Pancrazi, and Uribe (2011) who emphasize that the permanent shock plays an insignificant role in the SOE when financial frictions are incorporated.

Figure 2. Relative economics size in 2005



rate shock.

Using stochastic simulations of each estimated model we conduct variance decompositions of output growth and the consumption growth by exogenous source of variation. In the general equilibrium model the variance of each macroeconomic aggregate is allocated to four shocks: the permanent and transitory components of TFP in each of the two countries. In the partial equilibrium model the variance is allocated to the permanent and transitory components of home TFP and to the exogenous world interest rate. As such, the exercise thus allows us to gauge how much of the general equilibrium impact of the large region on the business cycle of the small open economy is captured by the interest rate process.

Our paper makes three contributions to the international business cycle literature. The first contribution of our study is that it covers a large set of countries (68) and a substantial period of history, 35 years. We discover that the persistence of the TFP shocks in developed and developing countries are significantly different, which is consistent with the findings by Aguiar and Gopinath (2007) who used a more limited cross-section. The second contribution is to provide a quantitative comparison of a two-country general equilibrium model with a small open economy model. We find that the partial equilibrium model and the general equilibrium model generate very similar variance decompositions when the shock processes are properly specified for both models. However, proper specification of the shock processes virtually presupposes the general equilibrium model as a starting point. This is because it is not possible to identify the shocks to the small open economy without knowing the structural relationship between the two economies. Consequently the sources of variance of business cycles in small open economies is mis-specified in the partial equilibrium approach. The third contribution is that we contrast the impact of oil price changes on the production of oil net exporters and net importers, given we have OPEC countries in our dataset. We find that the fluctuations in the relative price of oil contributes significantly to the business cycles of most economies. In particular, the oil price is procyclical (countercyclical) for net oil exporters (importers).

International Business Cycles

The data panel is drawn from the Penn World Tables (PWT) 6.2. The PWTs provide purchasing power parity and national income accounts converted to international prices for 188 countries from 1950 to 2005. We use GDP as the output measure and private consumption as the consumption measure. Based on data availability, the final panel contains 68 countries and the sample runs annually from 1970-2005.[3] Among the 68

[3] The 68 countries include: United Arab Emirates, Argentina, Austria, Belgium, Bangladesh, Bolivia, Brazil, Switzerland, Chile, China, Cote d'Ivoire, Cameroon, Colombia, Costa Rica, Denmark, Dominican Republic, Ecuador, Spain, Finland, Greece, Guatemala, Hong Kong, Honduras, Indonesia, India, Ire-

countries in the panel, 26 countries are developed countries and 42 countries are developing countries and based on the classification found in the International Monetary Fund's World Economic Outlook Report, April 2010.

One of the greatest challenges in addressing the business cycle heterogeneity of Figure 1 is the curse of dimensionality. Obviously, any attempt at modeling the aggregates or shocks using a standard unrestricted VAR model is hopeless given the number countries involved. Fortunately, Kose, Otrok and Whiteman (2003) introduced a Bayesian dynamic factor model to help overcome this challenge. In the dynamic factor model, a common world factor accounts for the comovement of the business cycles of all the countries, and thus significantly reduces the number of papers to be estimated.

Based on the KOW approach, we estimate the following dynamic factor model:

$$\Delta \mathbf{z}_{j,t} = \begin{bmatrix} \Delta y_{j,t} \\ \Delta c_{j,t} \\ \Delta i_{j,t} \end{bmatrix} = \begin{bmatrix} a_{j,y} \\ a_{j,c} \\ a_{j,s} \end{bmatrix} + \begin{bmatrix} b_{j,y} \\ b_{j,c} \\ b_{j,s} \end{bmatrix} f_t^{world} + \begin{bmatrix} c_{j,y} \\ c_{j,c} \\ c_{j,s} \end{bmatrix} f_{j,t}^{country} + \begin{bmatrix} \varepsilon_{j,t,y} \\ \varepsilon_{j,t,c} \\ \varepsilon_{j,t,i} \end{bmatrix}, \quad \text{(II.1)}$$

where the j denotes the country. The data vector, $\Delta \mathbf{z}_{j,t}$, contains the growth rate of real GDP, consumption and investment. As in KOW, the world factor and the country factor both follow an AR(3) process. The factor loadings on the world and country-specific factors are country-specific. The issues regarding identification and the method of estimation are elegantly described in Otrok and Whiteman (1998). KOW also included a third factor, a regional (geographic) factor, but they concluded that the regional factor explains only a small fraction of the variation of each variable. Therefore, we exclude the regional factor

land, Iran, Iraq, Iceland, Jamaica, Kenya, Korea, Kuwait, Libya, Sri Lanka, Luxembourg, Morocco, Mexico, Malaysia, Nigeria, Netherlands, Norway, New Zealand, Pakistan, Panama, Peru, Philippines, Portugal, Paraguay, Qatar, Saudi Arabia, Senegal, Singapore, El Salvador, Sweden, Thailand, Uruguay, Venezuela, South Africa, Zimbabwe, Australia, Canada, France, Germany, Italy, Japan, United Kindom, and United States.

in our model. Moreover, since the regional factor is orthogonal to the world factor and the country specific factor, excluding the regional factor wouldn't affect our estimation of the world factor.

KOW also use the Penn World Tables data. However, our data is different from KOW's in several aspects. First, our data source is PWT version 6.3, while KOW's is PWT version 5.5. Second, we have 68 countries in our sample, while KOW used 60 countries. Our sample consists of 59 countries from KOW's sample and adds China and 8 OPEC countries (Libya, Nigeria, Iran, Iraq, Kuwait, Qatar, Saudi Arabia, and United Arab Emirates). Third our sample period is from 1971 to 2005, while the sample period of KOW's data is from 1961 to 1990.

Beginning with Hamilton(1983), a number of authors have stressed the importance of oil price shocks during the sample period used here. Oil prices affect the macroeconomy through many different channels. Backus and Crucini (2000) developed a three-region model in which two regions trade manufactured goods (as in the original Backus, Kehoe and Kydland (1995) paper) and a third region produced oil. A supply reduction by the oil producing region is transmitted to oil importing nations through higher input costs in the two manufacturing regions, mimicking the textbook treatment of an oil price shocks as a 'supply shock.' In terms of measured productivity it is not unreasonable to assume the following structure: $\ln A_{jt} = \zeta_j \ln p^O_{jt} + \ln X_{jt}$, where p^O_{jt} is the relative price of oil (i.e. the price of oil imports relative to the domestic GDP deflator) and X_{jt} represents other factors that determine measured productivity (including true TFP shocks). The parameter ζ_j captures the magnitude and possibly the sign of the impact of the oil price shock. That is, ζ_j is expected to be negative for the net oil importers and positive for net oil exporters, especially the OPEC countries. Consider the following linear regression model:

$$\Delta y_{jt} = \alpha_1 \cdot \Delta p^O_{jt} + \alpha_2 \cdot I_j \cdot \Delta p^O_{jt} + \beta_{1t} \cdot D_t + \beta_{2j} \cdot D_j + \varepsilon^y_{jt} \tag{II.2}$$

where Δy_{jt} is the output growth rate and $p^O_{jt} \equiv \ln(P^o_t S_{jt}/P_{jt})$ is the relative price of oil in terms of the domestic CPI. That is, P^o_t is the world oil price in US dollars, S_{jt} is the nominal exchange rate between the U.S. and country j and P_{jt} is the consumer price index of country j. I_j is a dummy variable equal to 1 if country j is an net oil exporter and zero otherwise. Finally, D_t and D_j are time and country dummy variable to capture the year fixed-effect and the country fixed-effect respectively. Thus the impact effect of a change in the relative price of oil on output growth, after controlling for time and country-effects is $\Delta y_{jt}/\Delta p^O_{jt} = \alpha_1$, for net oil importers and $\Delta y_{jt}/\Delta p^O_{jt} = \alpha_1 + \alpha_2$ for the net oil exporters.

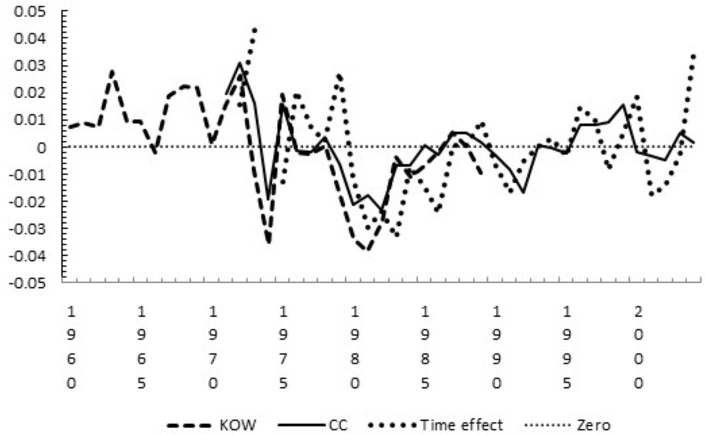
Table 1. Oil Price and Income Growth

	Coef.	Std. Err.	P-Value
α_1	-0.033	0.016	0.043
α_2	0.037	0.018	0.035
R^2		0.128	

The regression result is shown in Table 1. We can see that the value of coefficient α_1 is -0.033. This value is in line with Hamilton (2008)'s finding using the post-war data of the US. The value of coefficient α_2 is 0.037. Therefore, we have $\alpha_1 < 0$, and $\alpha_1 + \alpha_2 > 0$. In other words, an increase in Δp^O_{jt} will have a negative effect on Δy_{jt} of the oil net importers, and a positive effect on Δy_{jt} of the net oil exporters. This finding is consistent with our intuition that high oil prices will impede output growth of the net oil importers, while facilitate the output growth of the net oil exporters.

Returning to the factor model, Figure 3, presents three series: i) the world factor from the original KOW paper (1960 to 1989); ii) the world factor estimated using the model above and our panel (1971 to 2005) and iii) the year fixed-effects estimate in the

Figure 3. World business cycles



OLS regression above. First, we find that the estimated world factor is very robust to the inclusion of China and OPEC nations as well as a significant shift in the sample period of estimation. The second finding is that the year-fixed effects from the OLS regression with oil prices produces a similar trend to the world factor estimated from the full Bayesian dynamic factor model.

In summary, we have documented significant business cycle heterogeneity in terms of the volatility of GDP and consumption growth rates across countries. Despite this heterogeneity there remains a significant world business cycle and an important factor in the business cycle heterogeneity aside from productivity variation itself may be asymmetric responses to equilibrium movements in the relative price of oil across net exporters and net importers. With these facts in the background we turn, now, to a description of the model and how the stochastic properties of national and G-8 aggregate productivity shocks are estimated.

Models

The two country DSGE model developed by Baxter and Crucini (1995) has been a workhorse in the international real business cycle literature. This single-good, single-asset two-country general equilibrium model features trade in goods and a single non-contingent bond with the two countries potentially differing in relative economic size. Their model is a natural benchmark to compare with the standard small open economy model because as the size of one of the two countries converges to zero, the world interest rate becomes exogenous to the smaller of the two countries. This does not mean, however, that the joint stochastic process of domestic productivity and the world interest rate of the small open economy may be specified in an ad hoc fashion. Quite the contrary, the solution to the DGSE model is needed to determine precisely the shock process that mimics the general equilibrium solution. An important goal of our work is to see how closely the typical specification of the DSPE model mimics the true business cycle dynamics of the DSGE model.

Preferences and Technology

Individuals in each country have Cobb-Douglas preferences over consumption and leisure

$$U(C_{jt}, L_{jt}) = \beta^t \frac{1}{1-\sigma}[C_{jt}^{\theta} L_{jt}^{1-\theta}]^{1-\sigma}, \tag{II.3}$$

where parameter $\theta \in (0,1)$, and the intertemporal elasticity of substitution is $1/\sigma$.

All countries produce final goods using capital and labor. The production function is Cobb-Douglas and each country experiences stochastic fluctuations in the level of factor productivity, A_{jt},

$$Y_{jt} = A_{jt} K_{jt}^{1-\alpha} {N_{jt}}^{\alpha} \ . \tag{II.4}$$

The stochastic processes for productivity will involve permanent and transitory components each potentially with a component common across nations and unique to the nation. The processes are described in more detail and estimated in the next section.

The capital stock in each country, depreciates at the rate δ and is costly to adjust:

$$K_{jt+1} = (1-\delta)K_{jt} + \phi(I_{jt}/K_{jt})K_{jt}, \tag{II.5}$$

where $\phi(\cdot)$ is the adjustment cost function. As in Baxter and Crucini (1995), adjustment costs have the following properties: i) at the steady-state, $\phi(I/K) = I/K$ and $\phi'(I/K) = 1$ so that in the deterministic solution to the model the steady state with and without adjustment costs are the same and ii) the elasticity of the investment-capital ratio with respect to Tobin's Q is $\eta = -(\phi'/\phi'') \div (i/k) = 15$.

Closing the Models

Following Baxter and Crucini (1995), the two country DSGE model is closed by imposing one intertemporal budget constraint and world goods market clearing. The intertemporal budget constraint is:

$$B_{jt} + Y_{jt} - C_{jt} - I_{jt} - B_{jt+1}P_t^B = 0 \tag{II.6}$$

where B_{jt+1} denotes the quantity of bonds purchased in period t by country j. P_t^B is the price of a bond purchased in period t and maturing in period $t+1$. The bond is not state-contingent, it pays one physical unit of output in all states of the world. Implicitly this defines, r_t, the real rate of return for the bond (i.e., $P_t^B \equiv (1+r_t)^{-1} < 1$). The price of this bond is endogenous in the two-country equilibrium model, determined by the market-clearing condition in the world bond market.

The world goods market clearing condition is:

$$\sum_{j=0}^{1}\pi_j(Y_{jt} - C_{jt} - I_{jt}) = 0, \tag{II.7}$$

where π_j denotes the fraction of world GDP produced by country j. These weights are necessary because the quantities in the constraint are in domestic per capita terms. In our applications, $j = 0$, will be an aggregate of eight large industrialized countries while $j = 1$ will be a particular small open economy.

The small open economy is closed with an intertemporal budget constraint identical to (II.6) with the discount rate following an exogenous stochastic process describe below. In addition, the following boundary condition is imposed:

$$\lim_{t\to\infty} \beta^t p_{jt} B_{jt+1} = 0, \tag{II.8}$$

where p_{jt} is the multiplier on the intertemporal budget constraint of small open economy j.

Parameterization

All of the parameters except those governing the stochastic processes are set to common values across nations. Table 2 presents the calibrated parameter values used in our model.

Table 2. Calibrated parameters

Parameter	Value
β	0.954
σ	2
θ	0.233
α	0.58
δ	0.1

The value of β is set to be 0.954, so that the annual real interest rate is 6.5%. The parameter of relative risk aversion σ is 2 and labor's share α in the production function is 0.58. In the Cobb-Douglas preferences, the consumption share expenditure is: $\theta = 0.233$. The depreciation rate of capital, δ, is assigned a value of 0.10.

Results

Both the DSGE and DSPE versions of the model are driven by productivity shocks. It is well-known that there is a close correspondence between the productivity shocks one feeds into a IRBC model and the path of GDP that results. Put differently, with a large physical capital stock subject to adjustment costs, the internal propagation mechanisms of the basic neoclassical model typically account for a small part of output variance. This turns out to be quite useful for our purposes. Since the focus is on comparing two variants of IRBC models, it makes sense to match the observable properties of macroeconomics as closely as possible in choosing the stochastic productivity processes so that differences across the two models are clearly identified as differences in the model structure and not the model fit.

That said, it is not at all obvious what productivity processes are consistent with macroeconomic fluctuations in the large PWT cross-section, given the model. The indirect inference about TFP is a useful by-product of the quantitative exercises we conduct. We begin by describing the stochastic productivity specification used in the equilibrium model and the international business cycle moments matched to estimate parameters of that process. Next we conduct variance decompositions in the two-country general equilibrium model and the small open economy model to convey the trade-offs that exist in taking one approach or the other.

International productivity

The existing international business cycle literature emphasizes two key properties of total factor productivity. The first could be described as relating to the broader issue of technology diffusion. The notion that technical advances in one country spillover to others with a lag. Backus, Kehoe and Kydland (1992) modeled spillovers using a two-country VAR model under the null hypothesis that the level of total factor productivity is trend stationary. Thus, the off-diagonal element in their first-order autoregressive VAR captured the rate of productivity convergence. Baxter and Crucini (1995) allowed for non-stationary productivity variation and conducted co-integration tests between U.S. and Europe and U.S. and Canada. The persistence of the productivity gap was shown to be an essential ingredient in assessing the form of incomplete markets they modeled, which carries over to the current paper. If the country-specific component of productivity variation has a large permanent component, the wealth effects are significant and the lack of ex ante risk-sharing has significant consequences for business cycle dynamics and welfare. The recent literature has gravitated toward the view that productivity shocks are permanent which seems more consistent with the notion of technological adoption producing ever increasing productivity at an uncertain rate of progress. Since this literature is newly emerging and quite empirically demanding it should come as no surprise that the jury is still out on international productivity convergence, even among the industrialized world. Drawing on this literature, we consider the most flexible specification of productivity that the data allow.

Specifically, the logarithm of total factor productivity in country includes four components:

$$\ln A_{jt} = (\omega_j^P \ln A_{0t}^P + \omega_j^T \ln A_{0t}^T) + (\ln A_{jt}^P + \ln A_{jt}^T) \ , \tag{II.9}$$

where $j = 0$ is the G-8 index, $j > 0$ are the remaining 60 nations in our panel. The factor loadings ω_j^P and ω_j^T are the sources of common productivity movement across country j and the G-8 aggregate.

In each case, the permanent components evolve as random walks,

$$\ln A_{jt}^P = \ln A_{jt-1}^P + \ln \varepsilon_{jt}^P \tag{II.10}$$

whereas the transitory components are AR(1) processes

$$\ln A_{jt}^T = \rho \ln A_{jt-1}^T + \ln \varepsilon_{jt}^T. \tag{II.11}$$

The innovations to the permanent and transitory components of TFP, ε_{jt}^P, ε_{jt}^T, are *i.i.d.* draws from normal distributions with mean zero. The variance of the innovations varies across countries: $\varepsilon_{jt}^T \sim N(0, v_j^T \sigma_0^T)$, $\varepsilon_{jt}^P \sim N(0, v_j^P \sigma_0^P)$, $\varepsilon_{0t}^T \sim N(0, \sigma_0^T)$, and $\varepsilon_{0t}^P \sim N(0, \sigma_0^P)$, where σ_0^T and σ_0^P are the standard deviations of the innovations to the transitory and permanent components of TFP in the aggregated G-8 region. Thus, v_j^P and v_j^T, are the relative standard deviations of the corresponding innovations in the other 60 small open economies.

Productivity of the G-8

We calculate the weighted sum of annual output and consumption of the G-8 countries, which are denoted as y_0, c_0, and compute the second moments of GDP growth, consumption growth and the logarithm of the savings are, denoted Δy_0, Δc_0, and $y_0 - c_0$, respectively. The calibration strategy is to choose the appropriate value of $(\rho_0, \sigma_0^p, \sigma_0^T)$, so that the variance of $(\Delta y_0, \Delta c_0, y_0 - c_0)$ generate by the simulated model match their counterparts in the G-8 aggregate data. As the assumption underlying our approach is that the G-8 is by far the largest region and idiosyncratic movements in individual productivity of the G-60 have no discernible impact on the G-8, the calibration here is done in a closed economy (effectively setting $\pi = 1$ in the model).

The model is simulated 2,700 times with a range of the persistence parameter, ρ_0, restricted to the closed interval $[0.40, 0.95]$. The range of the innovation standard deviations of σ_0^p and σ_0^T are restricted to the closed interval $[0.006, 0.02]$. The outcome of the moment-matching exercise is that the three parameters, $(\widehat{\rho}_0, \widehat{\sigma}_0^p, \widehat{\sigma}_0^T)$ for the G-8 are equal to $(0.85, 1.1, 1.2)$. Table 3 compares the second moment properties of the data to the model simulation. The difference between the moments from the data and from the model is less than 10%.

Table 3. Matching second moments of G-8 aggregate

Standard deviation of:	Data	Model
GDP growth (Δy_0)	1.80	1.94
Consumption growth (Δc_0)	1.28	1.15
Inverse log savings ratio $(y_0 - c_0)$	1.44	1.32
G-8 productivity parameters		
$\widehat{\rho}_0$	0.85	
$\widehat{\sigma}_0^p$	1.1	
$\widehat{\sigma}_0^T$	1.2	

Productivity of small open economies in general equilibrium

To calibrate the productivity processes in the small open economies in the general equilibrium model, the two-country DSGE model is used (see Appendix A). The persistence of the transitory component of TFP is set equal to its G-8 counterpart, $\rho_j = 0.85\ \forall j$. While this choice is based on maintaining some aspects of symmetry across countries, it turns out this is equivalent to a quarterly persistence of 0.96 and thus consistent with the findings of Aguiar and Gopinath (2007). They estimated persistence of their transitory component of productivity at the quarterly frequency of 0.97 for Canada and 0.95 for Mexico, respectively. Moreover, they find this value is close to what the persistence of transitory component of productivity equals for a number of other developed countries as well.

Turning to the innovation variances of the components of productivity, the approach taken is as follows. Each of the 60 small open economies is taken in turn and combined with the G-8 and treated as the large and small open economies that populate the Baxter-Crucini two-country general equilibrium model. The model is simulated setting the relative size of the small country based on the fraction of world GDP it produces on average over the sample period of observation. The parameter settings of the persistence and innovation standard deviations in the of the G-8 forcing processes are maintained at the values of Table 1 no matter what country is paired with the G-8 aggregate. The open economy model is then simulated and a range of values for the relative innovation variance of the permanent and transitory shock to the small country is applied with the goal of matching: i) the variance of GDP and consumption growth of the country in question and ii) the correlation of GDP growth and consumption growth between the G-8 and the small open economy. The innovation standard deviations for the transitory and permanent components of the small open economy's productivity, v_j^T and v_j^P, are restricted to lie in the closed interval $[0.1, 15]$, with grid points at spaces of 0.1. The interval for the factor loadings on the permanent and transitory productivity of the G-8, ω_j^P and ω_j^T, is similarly diffuse $[-15, 15]$.

Table 4 reports the median parameters and points in the distribution of the values

Table 4. Small open economy productivity parameters

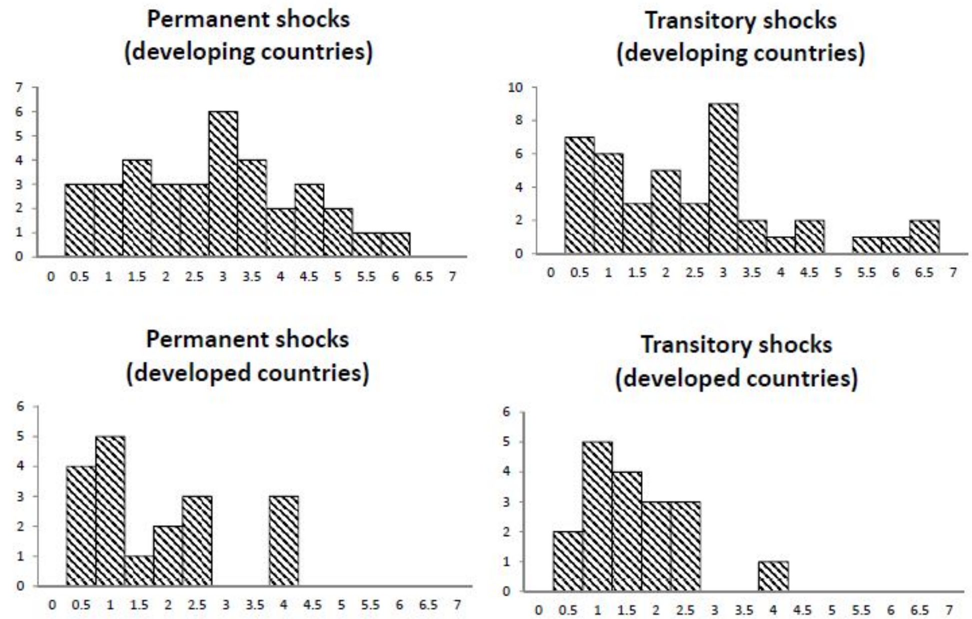
	Developing			Developed		
	1/3	Median	2/3	1/3	Median	2/3
ω_j^P	0	0.5	1.5	2	2	2
ω_j^T	0	0	0.5	0	0	0
v_j^P	2.1	2.9	3.9	0.7	1.0	1.9
v_j^T	1.2	2.0	2.7	0.7	1.3	1.6

of the calibrated parameters $(\omega_j^P, \omega_j^T, v_j^P, v_j^T)$ for developing and developed countries. Four patterns emerge. First, the factor loadings on the permanent component of the G-8 aggregate productivity shock (A_{0t}^P) is larger for developed countries than developing countries. For the median developed country, the value of ω_j^P is 2, while for the median developing country, the median value is actually 0. This finding is consistent with our intuition, as we normally consider that the developed countries are more technologically integrated with the G-8 than are the developing countries. The parameterization, does, however suggest a magnification effect of G-8 productivity on productivity variation of the small open developed nations.

Second, the stationary component of the productivity of the small economies appears unrelated to its counterpart in the G-8 aggregate. This is true for both developed and developing countries. The median for either group is ω_j^T. This fact shows that the comovement of productivities across countries are mainly driven by the comovement of permanent component, rather than the transitory component. If the transitory component of productivity is a proxy for policy changes and other shocks, it may not be surprising that they are idiosyncratic to the nations involved.

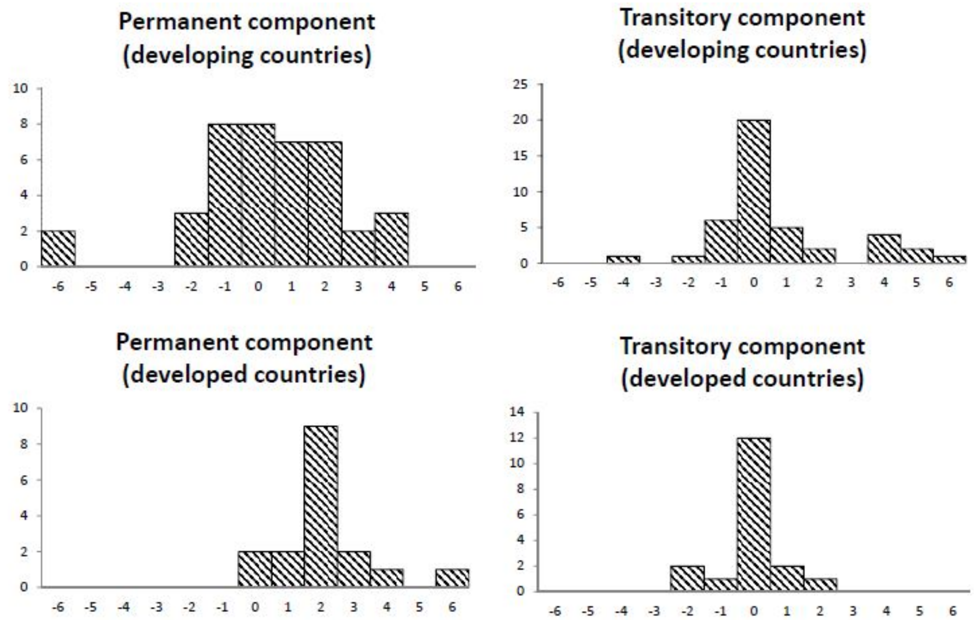
Third, for small economies, especially developing countries, the relative standard deviation of the innovations to the permanent component exceeds that of the transitory component in almost every case. Since these are relative to the G-8 values, it means the

Figure 4. Frequency distributions of standard deviation of productivity innovations relative to the G-8



permanent innovations are considerably elevated relative to the transitory component as we move from the G-8 to the emerging market economies. In fact, the median developing country has an innovation standard deviation 2.4 (1.6) times that of the G-8 aggregate for the permanent (transitory) component of national TFP. Recall that for the G-8 aggregate, the standard deviations of the permanent and transitory innovations were quite similar, 1.1 and 1.2 percent, respectively. Thus the median small country has permanent innovations dominating transitory ones by a factor of about 1.38. Thus small countries are subject to more productivity variation and, in particular, more permanent variation. This is important to recognize because, according to the simple permanent income model, the wealth effect of a unit innovation to the permanent component shock is much greater that of the transitory shock. The complete distribution of the four parameters across the small open economies are presented in Figure 4 and Figure 5.

Figure 5. Frequency distributions of factor loadings on G-8 productivity



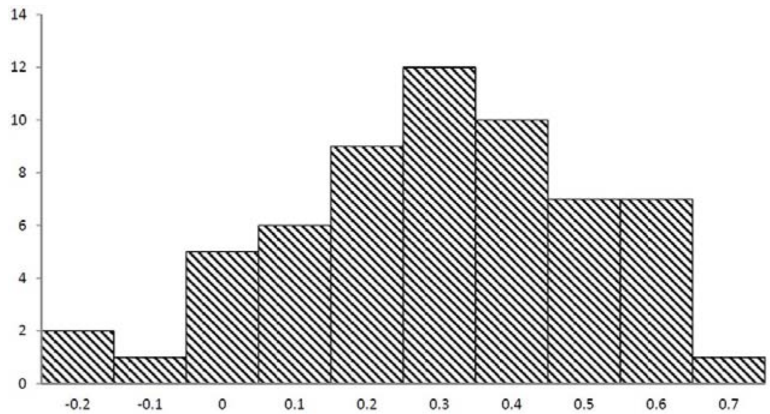
The presence of a permanent component in productivity in the small open economies that is shared with the G-8 region (i.e. the positive factor loading ω_j^P) is a key facet of the international business cycle model in terms of overcoming the comovement puzzle. That is, the fact that under complete international risk-sharing consumption correlations should be close to one while output correlations are often negative whereas empirically (in industrialized nations) the typically pair-wise correlation of output growth and consumption growth across countries is in the neighborhood of 0.25. Incomplete markets with a rich mix of permanent and transitory and common and idiosyncratic shocks allows a much closer match of theory to data.

Table 5 shows the cross-country distribution of the correlation of output growth and consumption growth between the G-8 region and small open economies. We have three findings. First, the output growth of developed countries are much more strongly correlated with the output growth of the G-8 region than developing countries. The median

Table 5. Correlation of Output Growth

	Developing			Developed		
	1/3	Median	2/3	1/3	Median	2/3
$\rho(\Delta y_{G8}, \Delta y_j)$	0.10	0.15	0.25	0.40	0.46	0.52
$\rho(\Delta c_{G8}, \Delta c_j)$	-0.08	0.03	0.10	0.24	0.33	0.42
$\Delta\rho^y_{M,D}/\rho^y_M$	-0.04	0	0.06	0.02	0.05	0.08
$\Delta\rho^c_{M,D}/\rho^c_M$	-0.12	-0.03	0.03	-0.09	-0.06	0

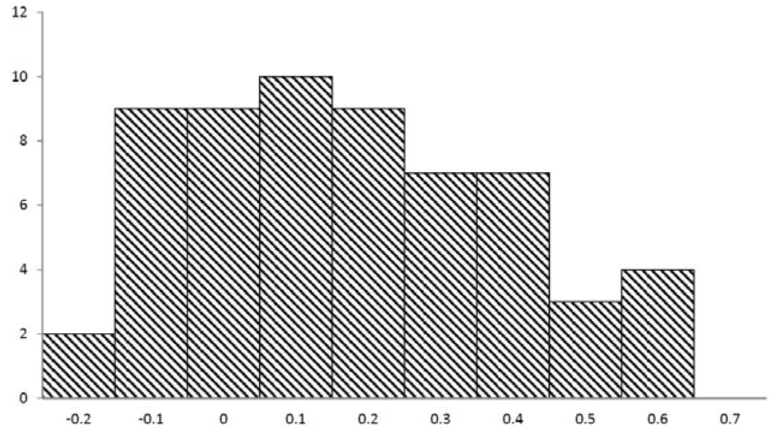
Figure 6. Small economy output correlations with the G-8



value of the correlation coefficient of output growth is 0.46 for developed countries, and 0.15 for developing countries. Second, consumptions are also positively correlated between the small open economies and the G-8 region for most economies, but are less positively correlated than output. The median consumption correlation coefficient for the developing countries is 0.03 for developing countries, and 0.33 for developed countries. The entire cross-country distribution of the international correlations are presented in Figure 6 and Figure 7. As is evident the consumption correlations are not only lower on average than the output correlations, they have less of a central tendency across countries.

To summarize, we find it is necessary to have both permanent and transitory productivity variation to match the business cycle movements of the small open economies in the panel. Moreover, the innovation variances of own-country productivity innovations are typically greater than that of the G-8 and quite diverse in the cross-section. One central

Figure 7. Small economy consumption correlations with G-8



tendency across both the developing and developed small open economies is the apparent lack of a role for a transitory component of the G-8 productivity to spillover to productivity in these countries. This seems plausible in the sense that the permanent component of productivity variation is more likely to true productivity while the transitory component is quite plausibly standing in for other policy and non-policy shocks which are likely to both transitory (fiscal shocks, terms of trade shocks) and idiosyncratic to the nation.

Productivity of small open economies in partial equilibrium

In moving to the partial equilibrium model, we assume the domestic and world TFP shocks are exactly the same stochastic processes as estimated using the GE model simulations earlier as this represents our null model. It is important to note that this presents a much richer stochastic model of TFP for the small open economies than is typical in the existing literature. For example, Mendoza (1991) modeled Canadian TFP as a simple AR(1) process whereas in our specification Canada's TFP will be the sum of the four components discussed above: permanent and transitory world productivity and permanent and transitory components of productivity unique to Canada.

Putting aside this issue, the key alteration in the move to partial equilibrium is the move from an endogenous equilibrium real interest rate to an exogenous real interest rate. In the two-country equilibrium model there are three state variables (the domestic and foreign capital stock and domestic bonds) and four shocks (each country's permanent and transitory component of productivity). Thus, the linear approximate solution of the model would produce deviations of the equilibrium real interest rate that is a linear function of all seven variables. Moreover, since the state and exogenous variables all follow first-order autoregressions, the autoregressive part of the equilibrium real interest rate would be of order seven. The moving average component would be of order 4 (given the four unique underlying shocks). The interest then would be an ARMA (7,4). Each additional country one adds to the general equilibrium model adds 4 more lags and 2 more shocks. While the quantitative importance of these state and exogenous variables falls as the size of the countries added to the model falls, it become quite unwieldy even in the three country case. Since the point of the exercise is to explore potential errors of prediction or interpretation that arise when the interest rate is modeled in a more ad hoc fashion, we assume as Mendoza (1991) did, that the discount rate follows an AR(1) process:

$$\ln P_t^B = \gamma_j \ln P_t^B + \ln \varepsilon_{jt}^B, \tag{II.12}$$

where $0 < \gamma_j < 1$ denotes the persistence of the logarithm of the bond price, and ε_{jt}^B is an *iid* draw from a normal distribution with zero mean and standard deviation σ_j^{PB}.

To parameterize the real interest rate we match the same second moments as before (namely, the variance of output and consumption growth), but use the partial equilibrium model of a small open economy as the simulation model. Table 6 shows the estimation results for the median and two points in the cross-sectional distribution of the 60 small countries. We observe three patterns in the table. First, the persistence of the bond price process is similar in both developing and developed countries. The median autocorrelation coefficient is 0.25 for developing countries and 0.23 for developed countries. Second, the median standard deviation of the innovation term is the same for developing and developed countries as well. This is reassuring since our approach presumes a single world real interest rate and full integration of international bond markets at that common rate. Obviously this is a very strong assumption, but at least the persistence and volatility of the real interest rate is similar across cases based on the simulation estimates. It is worth noting that the developing country group is more asymmetric than the developed country group as evident in the much higher persistence and innovation of the implied real interest rate in the tail of the distribution.

Table 6. Bond Price Shock Parameters

	Developing			Developed		
	1/3	Median	2/3	1/3	Median	2/3
$\widehat{\gamma}_j$	0.23	0.25	0.60	0.20	0.23	0.24
$\widehat{\sigma}_j^{PB}$	0.001	0.001	0.008	0.001	0.001	0.003

Variance decomposition

With the calibration of the DGSE and DGPE models complete, we are in a position to compute variance decompositions of consumption and output growth of each country into the underlying exogenous sources of variation using each modeling approach.

The two country general equilibrium model

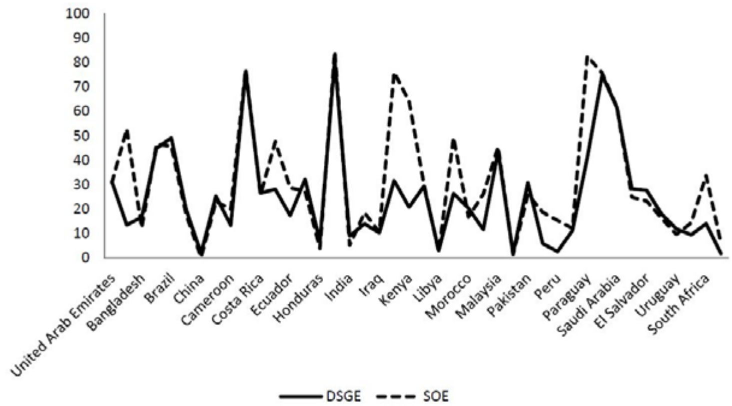
We start our variance decomposition from the two-country DSGE model. Table 7 shows the variance decomposition of output growth. Comparing the contribution of different components to the cyclical variation in GDP growth between developing and developed countries, three patterns emerge. First, domestic productivity shocks dominate the business cycles in developing countries, while the productivity shocks of the large economy (G-8) dominate the business cycles of the developed countries. For the median developing country, a sum of 15.7% (not shown) output growth variation is due to the productivity shocks originating from the large economy, compared to a much higher proportion of 51.5% (not shown) for the developed countries.

Second, if we focus on the domestic productivity shocks, the permanent component is quite comparable in importance as the transitory component for the developing countries (33.1% versus 33.6% for the medians). By contrast, for the developed countries, the transitory component vastly outweighs the permanent component, 24.6% compared to 3.9%. This particular finding is of interest in light of AG, who state that permanent productivity shocks are much more important in explaining output variation in developing countries than in developed countries. Our general equilibrium results show this is true when conditioning on shocks of domestic origin (the first panel). When examining the productivity linkages between the G-8 and other developed countries, the permanent shock is very important, accounting for 47.5% of the variance for the median developed country.

Table 7. Variance Decomposition of Output Growth in DSGE

		Developing			Developed		
		1/3	Median	2/3	1/3	Median	2/3
Domestic	ϵ_j^P	25.8	33.1	48.5	2.9	3.9	6.6
shocks	ϵ_j^T	16.4	33.6	51.7	17.0	24.6	32.4
G-8	ϵ_0^P	4.4	8.8	15.4	32.5	47.5	62.4
shocks	ϵ_0^T	1.4	6.9	11.6	2.9	3.9	6.3

Figure 8. Variance decomposition of output growth (developing countries)

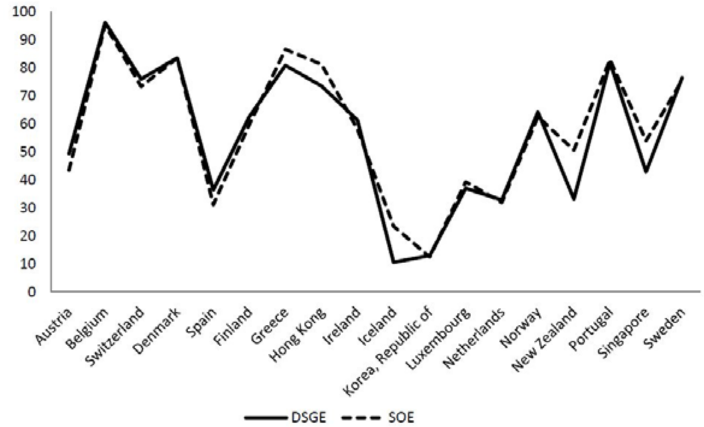


The small open economy model

The variation of output of small open economies is accounted by five different shocks in the small open economy model: domestic permanent and transitory TFP shocks, world permanent and transitory TFP shocks, and a world real interest rate shock. Figure 8 and Figure 9 plot the total variance accounted for the shocks originating outside of the home country in both the DSGE model and the DSPE model. In the DSGE model we are adding up the impact of the ε_{0t}^{P} and ε_{0t}^{T} shocks, the permanent and transitory shocks to G-8 productivity. In the general equilibrium model these shocks affect the smaller economies directly through their role in directly altering productivity in the smaller economies and indirectly through the transmission of business cycles from the large to the small countries. In the DSPE model, we are adding up the impact of the ε_{0t}^{T}, ε_{0t}^{P}, and σ_{j}^{PB} shocks.

Since the DGSE model is the null model, it gives the correct attribution of the variance to productivity in the G-8. In the developed country sub-sample, the misattribution of variance is relatively minor since the two lines track each other quite closely. In the developing country sub-sample are not necessarily larger on average, but they are clearly more concentrated in the cross section. For example, in the case of Kenya the partial

Figure 9. Variance decomposition of output growth (developed countries)



equilibrium model attributes almost everything to the shocks internal to the country whereas the correct answer is the opposite with most of the variation coming from abroad.

The more subtle problem with these comparisons has to do with the identification of the underlying sources of the shocks. Although the SOE model generates similar results to the DSGE model in variance decomposition, this was largely engineered by the fact that we built a rich stochastic structure where productivity in the small economies was in part determined by productivity in the G-8, through the factor loadings. This is rarely done in practice. Typically the only foreign variable entered into the state space of the small open economy model is the world interest rate. Unfortunately, the a simple first-order autoregressive model of the real interest rate is a poor proxy for the presence of foreign productivity in the list of exogenous variables. Table 8, for example shows a more disaggregated variance decomposition. According to the table, the real interest rate shock (bond price shock in our model) can only explain a negligible portion of output variation for both developed and developing countries in our SOE model. This is consistent with Mendoza's (1991) study of Canada using a small open economy model.

This creates the illusion that Canadian productivity is driving the Canadian business cycle. Given that productivity and output are highly correlated even in open economies such as Canada, one might be led to further argue that modeling Canada as a closed economy would be a good idea since doing so gives rise to a similar variance of Canadian GDP and contribution of productivity to that variation. There are two problems with this interpretation, which Table 8 lays bare. First, the spillover from G-8 productivity to the small open economy is about as large as it was in the general equilibrium model. By specifying Canada's productivity as partly originating in the G-8 group, a large 'transmission' effect found. In contrast, if we start with a small open economy model and proxy foreign productivity with the real interest rate, we learn very little about the true underlying origins of productivity changes or their international diffusion.

The other danger of modeling a country in partial equilibrium is that even the most careful measurement of productivity variation is likely to be contaminated by unmeasured variation in utilization of capital, labor hoarding and the impact of intermediate input variation, to name perhaps the most prominent. Consequently the movements in measured Canadian productivity are likely picking up equilibrium responses of Canadian consumers and firms to the broader general equilibrium.

Put differently, if it is important to identify the sources of productivity movements and determinants of the real interest, our results point to the value of the general equilibrium approach. Given that the motivation of developing general equilibrium models is at least in part to identify the shocks from the endogenous choices, it appears that this is very difficult to do in a small open economy setting. Moreover, matching the within sample moments gives no guarantee that a policy change or structural economy change will be adequately described with the small open economy model fit to a historical interest rate and domestic productivity process.

Table 8. Variance Decomposition of Output Growth in DSPE

		Developing			Developed		
		1/3	Median	2/3	1/3	Median	2/3
Domestic	ϵ_j^P	22.2	32.3	39.4	2.7	7.4	10.1
shocks	ϵ_j^T	6.2	33.0	52.3	15.8	22.6	34.1
Interest rate shocks	ϵ_j^{PB}	0.1	0.1	5.2	0.1	0.2	7.1
G-8	ϵ_0^P	1.8	3.8	9.8	23.9	42.1	48.9
shocks	ϵ_0^T	0.0	1.2	9.8	0.0	0.0	6.6

Concluding remarks

In this paper we have compared the performance of one-country SOE model with the two-country DSGE model. We conduct variance decompositions for the 60 small economies under the two-country general equilibrium framework and one-country small open economy framework. We find that the limitation of the SOE model is that it cannot capture the properties of permanent TFP shock from the foreign countries. This is particularly true, for the small developed countries, whose economic behavior is heavily influenced by permanent TFP shocks originating from the G-8, the SOE model tends to significantly underestimate the influences of the shocks originated from abroad.

CHAPTER III

Determinants of Business Cycle Comovement: A Factor Analysis

Introduction

Comovement of business cycles across countries has been of great interest to both academics and policymakers. The driving force of comovement has been extensively studied. One explanation of the comovement of output is input-output relationships. An input-output model with interdependencies between different sectors can naturally generate comovement of output at the sectoral level. For example, Long and Plosser (1983) develop a multi-sector dynamic stochastic general equilibrium (DSGE) model with dependent sectors and independent sector-specific productivity shocks. They show that producers in each sector have the incentive to smooth their output due to the interdependence between sectors, and thus comovement occurs. Crucini and Yilmazkuday (2009) develop a model that features interdependence of the services and manufacturing sectors, where services are the labor input to distribute the goods produced in the industry sector. Hence the output in the two sectors are strongly correlated. Moreover, a natural extension of this theory is to use it to explain the comovement of international business cycles. For instance, Ambler, Cardia, and Zimmermann (2002) present a multi-country and multi-sector model that can generate comovement of aggregate output across different countries. They find that the multi-sector model does perform better in capturing the international output comovement than the one-sector model.

The theory of input-output relationships is intuitive. Yet one critical difference between a one-country setting and a multi-country setting is that capital, goods, and labor move much more freely when they are within country borders. The restrictions and barriers on the international mobility of capital, goods, and labor may distort the transmission of shocks as we predict in the input-output relationships. Hence we have a natural question: What are the determinants of business cycle comovement, and by how much various the frictions in the goods, capital, and labor market affect risk sharing among countries? In the current literature, various determinants are proposed to explain the common characteristics of business cycles in both developed and developing economies, yet there is still disagreement on the most important factors driving the comovement of business cycles. Among many potential explanations of the comovement, three determinants are widely regarded as the main ones: trade, integration of international financial markets, and the spillover of TFP shocks.

Trade has long been regarded as a leading determinant contributing to business cycle comovement. The studies by Frankel and Rose (1998), Baxter and Kouparitsas (2005), and others show that bilateral trade has robust and positive correlation with business cycle comovement. Interestingly, international trade theories with a 'classic' Ricardian flavor normally predict a negative correlation between trade and comovement: As trade leads to higher industrial specialization, different countries will concentrate in different sectors. Therefore, in the extreme case of industrial specification, sector-specific shocks are essentially identical to country-specific shocks, and the business cycle comovement is minimal as sector-specific shocks are not shared across countries. For example, shocks to the country producing wines will not affect the country producing wools. One way to reconcile the classic theory and data is to introduce the inter-dependence of different sectors, such as the model in Ambler, Cardia, and Zimmermann (2002) shows: although different countries specialize in different sectors, most sectors are inter-dependent. In this way, sector-specific risks can be shared among countries. Another way to demonstrate the inter-dependency in a multi-sector and multi-country is to explicitly model the multi-stage of productions. For example, the multi-stage production model developed by Huang and Liu (2007) shows that trade of intermediate goods can directly generate positive comovement of production of two economies: The output of final goods depends on the import of the intermediate goods from another country. Thus the amount of imported intermediate goods is closely related to the quantity of the output of the final goods.

Financial development is also regarded as one important factor of business cycle comovement. Mechanisms of risk sharing through international capital market have been extensively explored in different aspects. First, completeness of the financial market is important to countries' risk-sharing. For example, in a two-country, one-good IRBC framework, Baxter and Crucini (1995) show that incomplete asset markets can generate reasonable output and consumption comovement of two countries given random-walk TFP shocks. Second, financial integration also contributes to the comovement of business cycles. Through a highly integrated financial sector, country specific shocks can be almost spontaneously transmitted from one country to another. As Imbs (2006) shows, financial sector integration increases the correlation of both output and consumption of different countries. To explain the correlation between the European debt crisis and the Great Recession from a theoretical aspect, Kollman, Enders, and Muller (2011) build a two-country dynamic stochastic general equilibrium (DSGE) model in which an exceptionally large loss of loans in one country would lead to a decline of production of a large magnitude in both countries, given the banking sectors of the two countries are highly integrated. Davis (2012) studies the heterogeneity of financial integration. He concludes that different types of financial integration can have different effects on business cycle comovement, due to their different implication on wealth effect. Third, studies also suggest that firms have motivations to share sector specific risks through international capital market in the highly industrialized countries. For instance, Kalemi-Ozcan, Sorensen, and Yosha (2003) find that risk sharing and industrial specialization are positively correlated. Highly specialized economies (regions) tend to insure against their sector specific shocks largely through capital market.

However, despite considerable theoretical and empirical evidence on positive correlation between financial openness and comovement, the role of integration of the financial sector still needs more examination. For instance, stylized facts of OECD data documented by Faia (2007) show that increase in financial openness would actually reduce output comovement. These facts are consistent with the theoretical work by Baxter and Crucini (1995) that two countries' business cycle comovement will be reduced if they have complete international asset market. Moreover, after investigating a large set of data, Kose, Prasad, and Terrones (2007) conclude that the risk sharing among countries is very limited, especially for developing and emerging countries.

Common productivity shock has been considered as the main reason for business cycle comovement in the recent literature. For example, Crucini, Kose and Otrok (2011) argue that the TFP shock accounts for the largest part of comovement for G7 countries. As for studies on productivity spillover from developed countries to developing ones, the mechanism of the comovement is intuitive: If all developing countries react to the same shock in the major advanced economy, say US, in a similar way, we would observe a comovement of those developing countries too. Canova (2005) and Mackoviak (2007) conduct their research along this approach, and they both find shocks from US play an important role on Latin American economies.

This paper studies two topics to shed some light on the relative importance of the determinants of comovement. First, we would like to summarize the properties of the comovement at the sectoral level using a dynamic factor model. Second, it is of our interest in the importance of financial integration in business cycle comovement.

The main results are as follows. First, we find evidence that supports the input-output relationship theory at the sectoral level. Second, financial openness is a plausible reason to explain the comovement of business cycles. Countries with closed financial markets tend to have strong business cycle comovement with the countries in the same group. This fact can shed lights on the globalization and decoupling puzzle documented by Kose, Otrok, and Prasad (2008). This is also consistent with the idea of Canova (2005) and Mackoviak (2007) that developing countries may have similar responses to the same shocks from major developed countries.

Methodology and Data

The theory of input-output relationship has rich implications for business cycle comovement at the sectoral level. In fact, our discussion on the determinants would be incomplete without studying the properties of productivity shocks themselves. Without loss of generality, we can write the dynamic processes of the outputs in the three sectors as

$$y_t = \begin{bmatrix} y_{a,t} \\ y_{i,t} \\ y_{s,t} \end{bmatrix} = A \begin{bmatrix} y_{a,t-1} \\ y_{i,t-1} \\ y_{s,t-1} \end{bmatrix} + \epsilon_t \tag{III.1}$$

Considering the properties of the three sectors, we approximately write down the weighting matrix A as

$$A = \begin{bmatrix} a & 0 & 0 \\ 0 & b & c \\ d & e & f \end{bmatrix}. \tag{III.2}$$

The parameterization of the above matrix A shows several properties and restrictions of the production process. First, agriculture is largely self-sufficient on the input side. The output of the agriculture sector does not depend on the output in the other two sectors, as the production in the agriculture sector requires fewer varieties of inputs than the other two. Thus the agriculture sector across countries should be the least correlated. Also, the agriculture sector should be the least correlated with the aggregate output for each country. Second, services are provided to nearly all the sectors in the economy. Thus, the services sector should be highly correlated with the aggregate output. On the other hand, the services sector's input structure is relatively simple comparing with the output structure. The key inputs are labor and various human capital. The simplicity of the input structure may reduce the comovement with the aggregate output. Third, the industry sector may have the most complex input structure among the three sectors, but its output structural may not be as complex as the services sector's.

The first step of my analysis is to calculate the correlation coefficient of each sector's output growth with GDP growth rate. I report the average correlation coefficient across all countries in our whole sample in Table 1. The results are consistent with our predictions from the input-output theory. The average correlation coefficient between agricultural output and aggregate output is 0.359. Comparing with the industry sector's 0.828 and services sector's 0.833, the agriculture sector is significantly less correlated with the aggregate output. The industry sector and the services sector have almost identical correlation coefficients.

Table 1. Average Correlation Coefficients of Sectoral Output and GDP

	Agriculture	Industry	Services
Corr. Coef.	0.359	0.828	0.833

Correlation of output at the sectoral level for different countries is more complicated. Especially, restrictions on trade and global financial market can prevent efficient allocation of inputs and outputs. I calculate the correlation coefficients of sectoral output for each country pair, and report the average value across country pairs in Table 2. It is intuitive that the output in the agriculture sector is almost independent in each country, as the major inputs affecting agricultural output are largely independent. Interestingly, correlation of the services sector is again almost identical to the industry sector. It is 0.110 for the industry sector, and 0.113 for the services sector.

Table 2. Average Correlation Coefficients of Sectoral Output Across Countries

	Agriculture	Industry	Services
Corr. Coef.	0.030	0.110	0.113

Do these correlation coefficients reflect the input-output relationship, or do they actually show the relative importance of trade and the international financial market? The choice of econometric methodology is essential to answer the above question. The proper econometric model needs to be able to address the following issues: i) identify the sources of fluctuations of the economics variables; and ii) be capable of handling a large set of countries. Meeting the above two requirements is almost infeasible for the standard VAR model. I have 46 countries and each country has output in three sectors, as well as consumption and investment. Therefore, even in a simple AR(1) model, we would have $(46 \times 46 \times 5)$ 10,580 coefficients and a variance-covariance matrix with a dimension of $(230, 230)$. It is not only difficult to estimate, but also to report. An alternatively to the standard VAR is the factor model. In a special factor model, the variance of all observables can be decomposed to the contributions of a constant, a world factor, a group factor, a country factor, and an idiosyncratic shock. Therefore, the number of coefficients is reduced to $(4 \times 5 \times 46)$ 920, and the variance-covariance matrix is not of our concern, as all shocks are idiosyncratic. Moreover, it is straightforward to analyze the comovement by identifying the effect of world factor and group factor. Thus a dynamic factor model meets the requirements of our study.

The Dynamic Factor Model

Dynamic factor models have gained popularity in recent years. The idea for those models is to use a small number if factors to drive fluctuations of many macroeconomic variables. This empirical methodology is also consistent with the implications of Long and Plosser (1983) that an exogenous shock can affect a set of input choices. For example, the comovement of variables across all countries can be captured by a world factor, and the comovement in a group of countries can be captured by a group-specific variable. In this way, we can significantly reduce the dimensions of variables in discussing a large set of countries.

In this paper, we employ the following dynamic factor model:

$$\Delta x_{ij,t} = \alpha_{ij} + b_{ij}^{W} F_t^{W} + b_{ij}^{G} F_{g,t}^{G} + b_{ij}^{C} F_{i,t}^{C} + \varepsilon_{ij,t} \quad . \tag{III.3}$$

Variable $\Delta x_{ij,t}$ on the left-hand side denotes the growth rate of the jth variable for country i. The variable F_t^W is the world factor that affects all variables in our model. The other two factors $F_{g,t}^G$ and $F_{i,t}^C$ are group-specific and country-specific factors respectively.

The idiosyncratic shock is captured by $\varepsilon_{ij,t}$. the coefficients of b_{ij}^W, b_{ij}^G and b_{ij}^C are called factor loadings, which measure the effects of the three factors. Specifically, we write the equation in the following form for each country:

$$\begin{bmatrix} \Delta agr_{i,t} \\ \Delta ind_{i,t} \\ \Delta srv_{i,t} \\ \Delta con_{i,t} \\ \Delta inv_{i,t} \end{bmatrix} = \begin{bmatrix} \alpha_{i,agr} \\ \alpha_{i,ind} \\ \alpha_{i,srv} \\ \alpha_{i,con} \\ \alpha_{i,inv} \end{bmatrix} + \begin{bmatrix} B_{i,agr}^W \\ B_{i,ind}^W \\ B_{i,srv}^W \\ B_{i,con}^W \\ B_{i,inv}^W \end{bmatrix} F_t^W + \begin{bmatrix} B_{i,agr}^C \\ B_{i,ind}^C \\ B_{i,srv}^C \\ B_{i,con}^C \\ B_{i,inv}^C \end{bmatrix} F_{i,t}^C + \begin{bmatrix} \varepsilon_{i,agr} \\ \varepsilon_{i,ind} \\ \varepsilon_{i,srv} \\ \varepsilon_{i,con} \\ \varepsilon_{i,inv} \end{bmatrix}. \quad \text{(III.4)}$$

The data vector on the left-hand side is the real value-added in the agricultural, industrial, and services sector, real private consumption, and real investment of country i. The world factor that affects all variables is F_t^W. The scale of each variable responding to the world factor is captured by factor loading $B_{i,j}^W$. Country-specific factor is denoted as $F_{i,t}^C$, and the factor loadings to the country factor is $B_{i,j}^C$. For each sector of country i, we can identify their comovement of output across countries by studying the loadings of the world factor parameter F_t^W. Similarly, the value of the loadings of of $F_{i,t}^C$ implies the comovement of each sector with other sectors within the same country.

The group factor is left out in the first estimation to identify the role of international trade. In the later stage of my estimation, I divide countries into three groups according to their financial openness, and group-specific factor will be added to the model.

The estimation of the model is Bayesian, which follows the procedures proposed in Otrok and Whiteman (1998), and used in other works, such as Kose, Otrok, and Whiteman (2003), and Crucini, Kose and Otrok (2011).

Variance Decomposition

As factors are orthogonal in our model, it is straightforward to use variance decomposition to measure the relative contribution of the world factor, group-specific factor, country-specific factor, and idiosyncratic component to the variation of each variable. Therefore, the variance of observable $\Delta x_{ij,t}$ can be written as:

$$Var(\Delta x_{ij,t}) = (b_{ij}^W)^2 Var(F_t^W) + (b_{ij}^G)^2 Var(F_{g,t}^G) + (b_{ij}^C)^2 Var(F_{i,t}^C) + Var(\varepsilon_{ij,t}) \quad . \qquad \text{(III.5)}$$

Thus the fraction of volatility due to factor X can be calculated as:

$$VD_{ij}^X = (b_{ij}^X)^2 Var(F_{X,t}^X)/Var(\Delta x_{ij,t}) \quad . \qquad \text{(III.6)}$$

Data

The output in the agricultural, industrial and services sectors are denoted by real value added in the agricultural sector, industrial sector, and services sector. Real consumption and real investment are denoted by real private consumption, and real capital formation. I calculate the growth rate of each variable and remove their means. The data is drawn from the World Bank's World Development Indicators (WDI) database. In the estimation I use annual data of 46 countries from 1976 to 2007[1]. As sector-specific variables are only available at the annual level, the choice of frequency of all observable is annual. The choice of country and time span is based on the availability of the data.

[1]This dataset includes 20 developed countries and 26 developing countries. The developed countries are: Australia, Austria, Canada, Denmark, Finland, France, Germany, Iceland, Italy, Japan, Korea, Luxembourg, Netherlands, Norway, Portugal, Singapore, Spain, Sweden, United Kingdom, United States. And the developing countries are: Bangladesh, Bolivia, Brazil, Chile, China, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, India, Indonesia, Iran, Kenya, Malaysia, Mexico, Morocco, Paraguay, Peru, Philippines, Senegal, South Africa, Thailand, Venezuela.

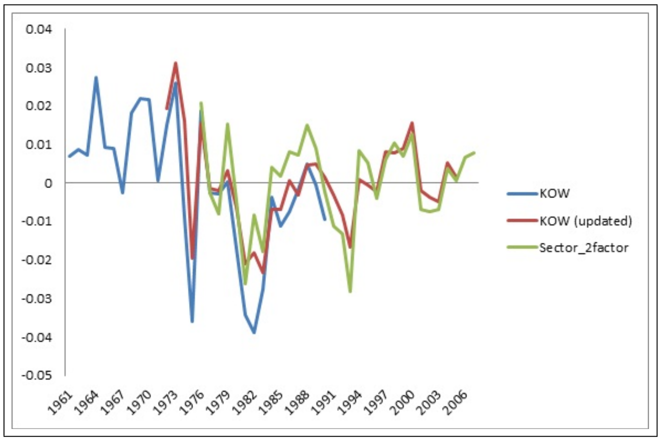
Information on country's financial openness is obtained from the KAOPEN index developed in Chinn and Ito (2006). This index covers 182 countries from 1970 to 2009. Most countries in our dataset are included in the index, except Luxembourg. The index is calculated based on a set of binary dummy variables codifying the tabulation of restrictions on cross-border financial transactions reported in the IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER). This index is based exclusively on regulations of each country. And it is not adjusted by other factors, such as country size. Hence this index is a *de jure* measure, rather than a *de facto* one. Although *de jure* and *de facto* measures have different implications in the study (for example, see the discussion by Tong and Wei (2011)), AREAER is still regarded as a leading source for studies in financial openness. Here I only use KAOPEN to get the result on financial openness.

Empirical Results

I compare my estimate of the world factor with four different measures of world business cycle: the world factor estimated by Kose, Otrok and Whiteman (2003), world factor estimated by the same methodology of KOW but with a updated dataset, and weighted average of demeaned real GDP growth rate of G8 (G7 and Australia). A graphical representation of the comparison is reported in Figure 1. We can see that all the measures are very similar to each other, despite they are from different sources, different methodology, and different time periods.

By conducting variance decomposition, the magnitude of comovement can be captured the proportion of variance accounted by the world factor. Therefore, $VD^W_{i,ind}$ and $VD^W_{i,srv}$ can well represent the comovement in the industrial and services sector. By comparing the values of the two variables, we can effectively reveal the information on the

Figure 1. The World Factor



comovement in the two sectors.

The summary of variance decomposition is showed in Table 3. There are several facts that are worth mentioning when we look at the variance decomposition of the world factor. First, the cross-country comovement of the agricultural sector is very weak for both developed and developing countries. The world factor only account for 1 percent of output variance for developed countries and 3 percent for developing countries. This fact is sensible as the productivity in the agricultural sector is generally lower than in other sectors, and the final output is to a large extent controlled by idiosyncratic factors, such as weather condition, flood, pest, contagious diseases for animals, and so on. Second, the world factor explains a much larger proportion of variation in the industrial sector, services sector, consumption, and investment for the developed countries than the developing countries. The median values of $VD^W_{i,ind}$ and $VD^W_{i,srv}$ are 16 and 19 percent respectively for developed countries, while the same median values for developing countries are only 2 and 3 percent. The much higher values of $VD^W_{i,ind}$ and $VD^W_{i,srv}$ show that there is more production synchronization among developed countries. Third, the comovement in private consumption and investment is also higher in developed countries. The median values of $VD^W_{i,con}$ and $VD^W_{i,inv}$ are 10 and

21 percent respectively for developed countries, while only 2 and 1 percent for developing countries. Fourth, comovement of the investment is much stronger than consumption for developed countries. For the advanced economies, the world factor contributes 21 percent to the variance of the investment, while only 10 percent to the variance of the consumption.

Moreover, there are several interesting results on the country factors as well. First, the output in agriculture sector is more strongly correlated with the whole economy for developing countries than developed countries. The country factor accounts for 15 percent of output variation in the agriculture sector for developing countries, while only 3 percent for developed countries. Therefore, this finding reflects the fact that the agriculture sector in general is much more important for the developing countries than developed countries. Second, the services sector and industry sector have similar magnitude of comovement with the whole economy for the developed countries. The country factor accounts for 38 percent of output variation of the services sector, while 32 percent of the industry sector. In fact, the world factor and the country factor both account for a similar portion of variance for industry and services sectors. This fact holds true for both developed and developing countries. It is consistent with the implication of the model developed by Crucini and Yilmazkuday (2010), where the output of the services sector is the value of efforts to distribute the products from the industry sector. Third, for developed countries, the country factor contributes more to the variance of the output of the services sector than the industry sector. And for the developing countries, country factor contributes less to the variance of the output of the services sector. This difference may reflect the fact that labor is relatively cheap in the developing countries. This finding is consistent with the estimation results in Chen (2013), where the author finds that the labor income share in developing countries is generally lower than in developed countries. Fourth, country factor is more important for developing countries than for developed countries. The median value of the fraction of variance in industry and services sectors is approximately 10 percent lower for developed countries than for developing countries. Nearly half of the output variance in the industry sector is captured by the country factor for developing countries. This is consistent with our previous finding that world factor is more important for developed countries. As markets are less open for developing countries, their domestic sectors are more closely related. Fifth, the country factor accounts more of the variation in the consumption than the investment for developing countries. Half of the variation of consumption for developing countries is captured by the country factor, while only 35 percent of investment is captured by the same factor. Lower factor loadings on the investment show that both goods and financial markets in the developing countries have more frictions.

Table 3. Variance Decomposition (Median) for Developed and Developing Countries

Developed Countries			
	World	Country	Idiosyncratic
Agriculture	0.01	0.03	0.93
Industry	0.16	0.32	0.38
Services	0.19	0.38	0.41
Consumption	0.10	0.37	0.46
Investment	0.21	0.37	0.30
Developing Countries			
	World	Country	Idiosyncratic
Agriculture	0.03	0.15	0.80
Industry	0.02	0.49	0.44
Services	0.03	0.45	0.48
Consumption	0.02	0.50	0.48
Investment	0.01	0.35	0.61

To get more detailed information on the comovement of countries, I also check the distribution of variance decomposition of industrial and services sectors for developed and developing countries, which is reported in Figure 2 and Figure 3. Several facts emerge from the figures. First, the comovement reflected by the effects of the world factor is very weak

Figure 2. Variance Decompostion of the World Factor for Developed Countries

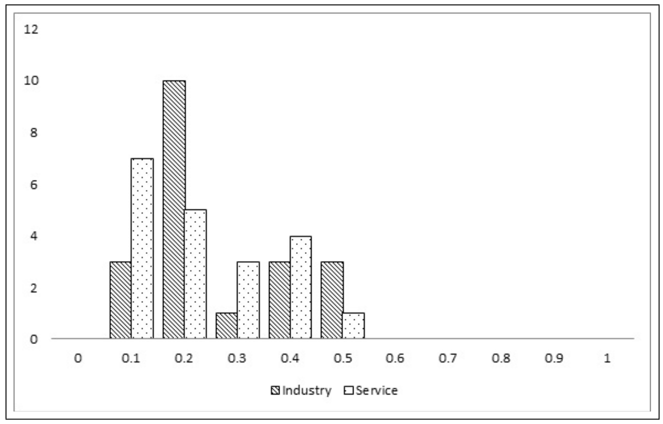


Figure 3. Variance Decompostion of the World Factor for Developing Countries

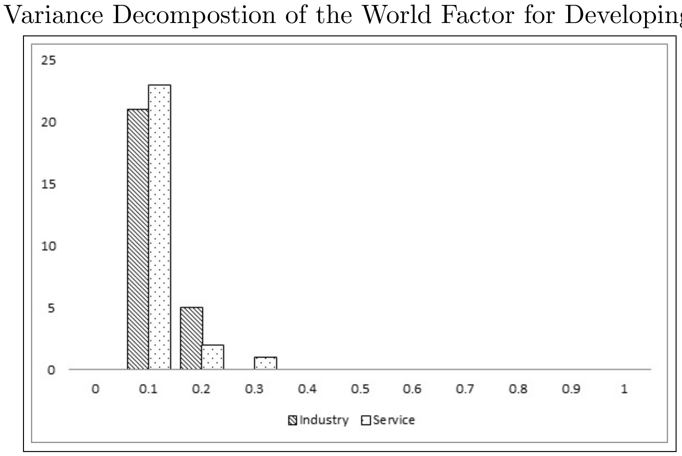
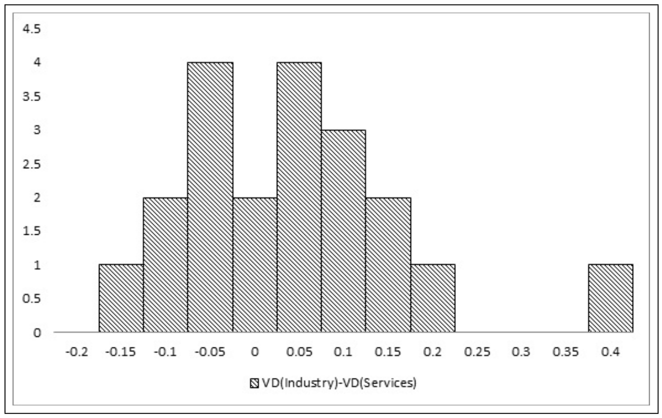


Figure 4. Difference between Industry and Services Sectors for Developed Countries



in both industrial and services sectors for all of the developing countries. Second, developed countries show stronger comovement in both industrial and services sectors. However, it is not obvious whether the comovement in the industrial sector surpasses the comovement in the services sector. In fact, I take the difference of $VD_{i,}^{W}ind$ and $VD_{i,srv}^{W}$, and Figure 4 shows the distribution of $(VD_{i,}^{W}ind - VD_{i,srv}^{W})$ for developed countries. We find that the values are very symmetric around zero. The comovement in the industry sector is not significantly higher than in the services sector.

Extension: Comovement and Financial Openness

Hypothesis and The Econometric Model

Unlike international trade that has stronger effect on industrial sector, financial sector affects the economy by allocating capital into the most efficient sector. Thus financial institutions may have more uniform impacts on both industry and services sectors, especially for the countries with highly developed financial markets.

To incorporate financial openness into the discussion, I estimate the following factor model:

$$\begin{bmatrix} \Delta agr_{i,t} \\ \Delta ind_{i,t} \\ \Delta srv_{i,t} \\ \Delta con_{i,t} \\ \Delta inv_{i,t} \end{bmatrix} = \begin{bmatrix} a_{i,agr} \\ a_{i,ind} \\ a_{i,srv}t \\ a_{i,con} \\ a_{i,inv} \end{bmatrix} + \begin{bmatrix} B^W_{i,agr} \\ B^W_{i,ind} \\ B^W_{i,srv} \\ B^W_{i,con} \\ B^W_{i,inv} \end{bmatrix} F^W_t + \begin{bmatrix} B^C_{i,agr} \\ B^C_{i,ind} \\ B^C_{i,srv} \\ B^C_{i,con} \\ B^C_{i,inv} \end{bmatrix} F^C_{i,t} + \begin{bmatrix} B^G_{i,agr} \\ B^G_{i,ind} \\ B^G_{i,srv} \\ B^G_{i,con} \\ B^G_{i,inv} \end{bmatrix} F^G_{o,t} + \begin{bmatrix} \varepsilon_{i,agr} \\ \varepsilon_{i,ind} \\ \varepsilon_{i,srv} \\ \varepsilon_{i,con} \\ \varepsilon_{i,inv} \end{bmatrix} \tag{III.7}$$

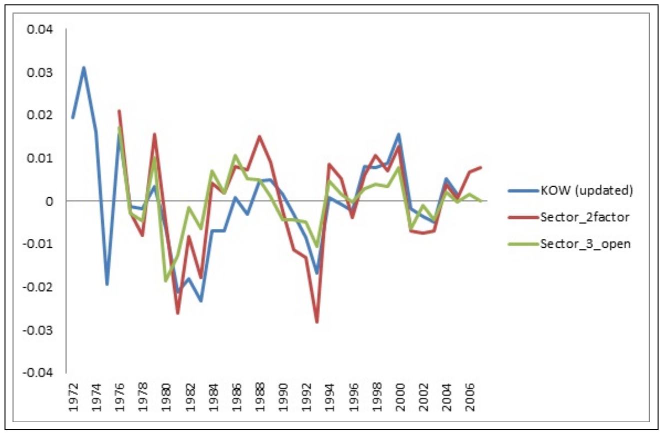
While the world factor and country factor remain the same as the previous estimation, I add a group specific factor, $F^G_{o,t}$, into the factor model. I divide the sample into three groups: financially open, semi-open, and closed countries[2]. It is worth mentioning that the criteria of dividing countries into groups is note unique. As developed and developing countries have distinct difference in many aspects, different criteria may result in very similar groups of countries. Therefore, our estimation results may have other potential explanations.

Empirical Results

The starting point of our empirical results is still the world factor. Figure 5 plots the world factor estimated by equation (3) and equation (4), and alternative world business cycle measures. I find the new estimate of the world factor by equation (4) is still very

[2]Countries that are financially open: Austria , Finland , Sweden , Denmark , Australia , Canada , Germany , Indonesia , Japan , Luxembourg, Malaysia , Netherlands , Singapore , United Kingdom , United States. Countries that are financially semi-open: Guatemala , Korea, Norway , Portugal , Senegal , Spain , Thailand , Venezuela , France , Italy , Bolivia. Countries that are financially closed: Bangladesh , Brazil , Chile , China , Costa Rica , Dominican Republic , El Salvador , Honduras , Iran, Peru , South Africa , Colombia , Iceland , India , Kenya , Morocco , Paraguay , Philippines , Ecuador , Mexico.

Figure 5. The World Factor



close to the previous one estimated by equation (3), as well as alternative measures of world business cycle. The estimate of world factor is robust to the change of empirical model.

Table 4 reports the median values of variance decomposition of the three groups of countries. Interestingly, the financial openness indicator plays an important role for the countries with a closed financial market. In the group of financially closed countries, the median values of $VD^G_{i,ind}$ and $VD^G_{i,srv}$ are 8 and 12 percent respectively. For the same group of countries, the world factor only accounts for 3 percent and 1 percent of variance of the industry and services sector. In other words, financially closed economies have stronger comovement within the group. In contrast to the financially closed economies, the world factor accounts for a much larger portion of the output variation in the industrial and services sector. The median values of $VD^W_{i,ind}$ and $VD^W_{i,srv}$ are both 11 percent for the financially open group, while the group specific factor does not explain a large portion of the output variation in the two sectors: The median values of $VD^G_{i,ind}$ and $VD^G_{i,srv}$ for the financially open countries are both only 2 percent. Considering the mutual effect of the world factor and the group factor, I find that the comovement of financially open countries is mainly led by the world factor, while the comovement of the financially closed countries is mainly led by group factor. In this sense, we can divide the world into two groups that have distinctively different business cycles. This result seems to support the theory depicted in Canova (2005) that developing countries may have similar responses to the same shock in the major developed country.

Table 4. Variance Decomposition: Comovement in Industry and Services Sectors for Three Groups of Countries

	Industry		Services	
	World	Group	World	Group
Closed	0.03	0.08	0.01	0.12
Semi-open	0.06	0.04	0.04	0.06
Open	0.11	0.02	0.11	0.02

Concluding Remarks

In this paper, I study the business cycle comovement at the sectoral level for 46 countries. Theoretical models suggest that interdependencies between different sectors can lead to output comovement at the sectoral level, and the same type of interdependencies can result in business cycle comovement across countries. My factor analysis shows that the agriculture sector is least correlated with other sectors. The comovement of industry and services sector shows very similar patterns. This fact supports the input-output theory in a multi-country framework. Evidence also supports that output in the services sector can be viewed as efforts to distribute the products in the industry sector. Moreover, I examined the role of financial openness in explaining the business cycle comovement. I find that the financially closed countries have stronger comovement within their group. This result suggest that the world economy diverges into two groups: the developed countries and the developing countries. The comovement of the developed countries may be explained by sufficient risk-sharing, while the comovement of the developing countries may result from the similar response to the shocks from the developed countries.

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