Financial Integration and International Risk Sharing

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Abstract

Conventional wisdom suggests that countries that are more financially integrated can better insure against risk. Despite widespread deregulation and financial integration in recent history, there is little evidence that countries have increased risk sharing. This work shows financial integration does not necessarily lead to significant improvement in risk sharing if financial contracts are incomplete and enforceability of debt repayment is limited. We use a calibrated DSGE model featuring a continuum of countries and their default choices on sovereign debt, and we model increased financial integration with an exogenous reduction in transaction costs on foreign assets. The seemingly large increase in capital flows is too limited to significantly improve international risk sharing due to default risk; if the default risk was eliminated, capital flows would be six times greater than the observed flows in the data, and international risk sharing would increase substantially. In addition, consistent with the empirical evidence, the model exhibits a greater frequency of sovereign default in the more-integrated period. Equilibrium defaults overall reduce international risk sharing because countries are excluded from markets for some period after default though it provides some contingency in current repayments.

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1 Introduction

Over the last two decades, the world witnesses widespread liberalization of capital controls. The World Economic Outlook (2002)[5] examines official restrictions on cross-border capital flows and documents that capital controls loosen substantially. As a result, countries have become more financially integrated over time. Kose, Prasad, Rogoff, and Wei (2003)[26] and Lane and Milesi-Ferretti (2003)[20] show that actual capital flows increase dramatically in recent decades. In particular, the ratio of the net debt position and GDP for 43 developed and emerging economies more than doubles; it increases from 8% in the less-integrated period 1970–1986 to 18% in the more-integrated period 1987–2004.[1]

Conventional wisdom predicts that countries should better insure macroeconomic risk when they are more financially integrated after such widespread deregulation. This work, however, shows that the liberalization of capital controls does not necessarily lead to a significant increase in international risk sharing if contracts are incomplete and enforceability of debt repayment is limited. The default risk on sovereign debt is the implicit impediment to capital flows and constrains the degree of financial integration. The seemingly-large financial integration is too limited to significantly improve risk sharing. In addition, financial integration is accompanied by a greater frequency of sovereign default and this hurts international risk sharing.

The basic framework we use is a dynamic stochastic general equilibrium (DSGE) model with a continuum of small open economies. Financial contracts have two features. First, contracts are incomplete; only uncontingent bonds are traded. Second, enforceability on debt repayments is limited; countries have the option to default on their debt, but lose access to financial markets and suffer from drops in output for some period after the event of default. Countries incur transaction costs on foreign assets, and we model financial integration with an exogenous reduction in the transaction costs.

The empirical observations motivate our modeling choices. We focus on debt contracts because debt accounts for the majority of foreign asset positions across countries: over 70% in terms of gross positions and over 60% in terms of net positions for our 43 countries. Kraay, Loayza, Servén and Ventura (2005)[19] also document that roughly three-quarters of net north-south capital flows take the form of net lending. Equity and FDI flows are rather limited given the well-established equity home bias puzzle and underdeveloped equity mar-

[1]The sample consists of 21 developed countries and 22 more-financially-integrated developing countries based on Kose et al. (2003)[26]. See Data Appendix 1 for detailed data description.

kets in the emerging markets.[2] Recurrent episodes of sovereign default in the data motivate us to model the default risk and equilibrium default. Empirically, the widespread deregulation of capital controls triggers financial integration. Thus we model increased financial integration as a result of a reduction in the transaction costs.

To quantify the model's implications, we first calibrate the model to the data. In particular, to capture rich features of TFP processes in the data, we estimate the world productivity process with a regime-switching process. The transaction cost is set to match the observed world capital flows in the data for each period: the less-integrated period and the more-integrated period. We then contrast quantitative implications of the model across these two periods. We find that the degree of international risk sharing, measured by the regression analysis is very limited in both periods. More important, international risk sharing increases little though capital flows have doubled in response to the reduction in the transaction cost.

The key to understanding limited risk sharing in both periods is the default risk, which is the implicit barrier to capital flows and impediment to international risk sharing. First, the default risk constrains borrowing because creditors never offer debt contracts that will be defaulted upon with certainty, and they charge an interest rate premium for debt with positive default possibilities. Moreover, borrowing is more constrained during recessions, a common feature of incomplete markets. Non-contingent repayment is more costly during bad times, and so countries are more likely to default, which leads to a higher interest rate schedule. Thus, the default risk generates a time-varying impediment to international risk sharing; borrowing is the most difficult when countries need it the most: in bad times. Second, default arises in equilibrium under incomplete markets, and equilibrium default hurts risk sharing overall. Though defaulting countries get some reliefs of an otherwise sharp drop in current consumption,[3] they lose access to markets and suffer reduced output for some period afterward. Weighing both effects, we find equilibrium default costly in terms of risk sharing.

The reduction in the transaction cost stimulates borrowing and lending, which endogenously generates financial integration. However, the increase in capital flows is still too small to significantly improve risk sharing due to the default risks. If the default risks were eliminated, capital flows in the more-integrated period would be six times larger than the observed flows in the data, and international risk sharing would improve substantially. In addition, the model produces a greater frequency of sovereign default as countries borrow more in the

[2] See Tesar and Werner (1995)[31].

[3] As argued by Grossman and Huyck (1988)[14], the option to default helps complete markets by making uncontingent payments state-contingent.

more-integrated period. This worsens international risk sharing. Thus, international risk sharing improves little when financial integration is plagued with sovereign default risk and incomplete markets.

Our work helps explain why the large empirical literature, motivated by the conventional wisdom, finds little evidence of better international risk sharing over time despite the observed increase in financial integration. Kose, Prasad, and Terrones (2006)[18] offer an extensive review of the literature and document that international risk sharing improves little among 176 countries, and even declines for emerging markets, which experienced a large increase in cross-border capital flows.

The model also generates several important predictions that are consistent with the data. First, the model predicts that the default rate increases in the more-integrated period when countries borrow more in response to the reduction in the transaction cost. Data provided by Standard & Poor's indicate that the average fraction of countries in default has nearly doubled from 5% in the less-integrated period to 9% in the more-integrated period. Second, the model predicts that countries with a default history have worse risk sharing than those without a default history. Dividing our sample into these two groups, we find the same pattern in the data. Third, the model predicts that default often occurs at bad times and that defaulting countries have higher debt relative to output. Reinhart, Rogoff, and Savastano (2003)[27] documents that over a sample of 27 middle-income countries, defaulting countries on average borrow more in terms of output than non-defaulting countries.

Our model builds on the sovereign default literature pioneered by Eaton and Gersovitz (1981)[11] and advanced by Arellano (2007)[2], Aguiar and Gopinath (2006)[1], and Yue (2005)[33]. All these studies examine features of sovereign default under a pure exchange setup. Our work models sovereign default in the production economy, which is more suitable for studying roles of financial integration on international risk sharing. Models with pure exchange economies attribute any smoothing in consumption in the data to financial integration because there is no means to smooth consumption in financial autarky. This will overestimate the role of international financial markets on risk sharing because variability of consumption is lower than that of output even in closed economies where countries smooth consumption using domestic capital stocks.

Our work is not the first theoretical study of the impact of financial integration on international risk sharing. Mendoza (1994)[24] studies a small open economy RBC model, calibrated to Canada and Mexico, to illustrate that variability of consumption relative to output is not sensitive to the observed degree of financial integration resulting from a looser exogenous borrowing constraint. Our work endogenizes borrowing constraints with sovereign default risk and generates time-varying impediments to risk sharing. Perri and Heathcote (2004)[16] address the phenomenon of lower consumption co-movement between the U.S. and Europe under increased cross-border equity and FDI flows as a result of less-correlated shock processes. We are interested instead in risk sharing between developed countries and emerging markets, and focus on the impact of increased debt flows, as these account for the majority of north-south capital flows. In their theoretical work, Broner and Ventura (2007)[7] show that globalization may hurt both international and domestic risk sharing if governments can not discriminate between domestic agents and foreign agents when choosing whether to enforce contracts. In their model, the only reason that governments enforce repayments to foreigners is to safeguard domestic asset trade. In contrast, it is the reputation and sanction mechanisms that sustain sovereign debt repayments in our quantitative work. Thus, our work is complementary to the existing work.

The organization of the paper is straightforward. Section 2 lays out the theoretical model. We parameterize the model, present and analyze the quantitative results in section 3. Section 4 provides further analysis on the model implications and section 5 concludes.

2 Model

This section presents the theoretical framework designed to model the impact of financial integration on international risk sharing. The basic framework is similar to that in Bai and Zhang (2005)[4]. There are a continuum of small open economies and a large number of international financial intermediaries. All economies produce a homogeneous good that can be either consumed or invested. Financial intermediaries perform the functions of international financial markets, pooling savings and loaning funds across countries. Two key frictions exist in international financial markets. First, the markets are incomplete; only uncontingent debt claims are traded between financial intermediaries and countries. Second, debt contracts have limited enforcement; that is, countries have the option to default on their debt. Different from Bai and Zhang (2005)[4], we model the default choice explicitly, and default could arise in equilibrium. We start with introducing the problems of each individual country and financial intermediaries and then present some characterization of the recursive equilibrium.

2.1 Individual Country

Each country consists of a representative, infinitely-lived consumer and a production technology.[4] Countries face different shocks in their production technologies, the feature of which is the key source of heterogeneity across countries. The production function is given by the standard Cobb-Douglas $aK^{\alpha}L^{1-\alpha}$, where a denotes the country-specific idiosyncratic shock to total factor productivity (TFP), K the capital input, L the labor input, and α the capital share parameter. The TFP shock a follows a first-order Markov process with finite support A and transition matrix Π . With a continuum of small open economies and idiosyncratic TFP shocks across countries, the model has no aggregate uncertainty.

The utility of the representative consumer is given by

$$E_0 \sum_{t=0}^{\infty} \beta^t u(C_t) \tag{1}$$

where C denotes consumption, $0 < \beta < 1$ the discount factor, and u utility satisfying the usual Inada conditions. Labor supply is inelastic. We normalize each country's allocation by its labor endowment, and let lowercase letters denote variables after normalization. The production function simplifies to $f(k) = ak^{\alpha}$.

In each period, a country is either in the *normal phase* or in the *penalty phase*. Countries in the normal phase have access to international financial markets, while countries in the penalty phase lose their access and suffer from a drop in TFP. The state of each country is summarized by $x = (s, h)$, where h denotes its phase with $h = N$ indicating the normal phase and $h = P$ indicating the penalty phase; $s = (a, k, b)$ denotes its productivity shock a, capital stock k and bond holding b. Let $X = S \times H$ be the state space with $S = A \times \mathbb{R}_+ \times \mathbb{R}$ and $H = \{N, P\}$.

The timing is as follows. At the beginning of each period, the TFP shock is realized for each country and publicly observed by all agents. Next, countries in the normal phase decide whether or not to default and also choose its consumption, investment and bond holdings according to their default decisions. Countries in the penalty phase cannot borrow or save abroad and so only decide on consumption and investment. Countries in different phases face different constraints, and so we examine their problems in turn.

[4]Here we consider each country's planning problem. It can be decentralized similarly as in Kehoe and Perri (2004)[17], where consumers decide borrowing from abroad while governments make default choices and levy capital income taxes.

Country in the Normal Phase

A country s in the normal phase can choose whether to default on its outstanding debt by comparing the respective welfares, so its value function $V(s, N)$ is given by

$$V(s, N) = \max\{W^R(s), W^D(a, k)\} \tag{2}$$

where $W^R(s)$ denotes the repayment welfare and $W^D(a, k)$ the default welfare. Let d denote the default decision with $d = 0$ indicating repaying and $d = 1$ indicating defaulting. Country s chooses to repay $d(s) = 0$ if and only if $W^R(s) \geq W^D(a, k)$.

If it defaults, the country gets its debt written off, but it will be penalized. First, today the country suffers a loss in TFP[5] and cannot access international financial markets. Second, from the next period on the country will stay in the penalty phase until it returns to the normal phase. Thus, country s chooses only consumption c and next-period capital stock k' to maximize the default welfare give by

$$W^D(a, k) = \max_{c,k'} u(c) + \beta \sum_{a'|a} \pi(a'|a) V(a', k', 0, P) \tag{3}$$

subject to

$$c + k' - (1 - \delta)k \leq (1 - \gamma)ak^{\alpha} - \Phi(k', k), \tag{4}$$

and

$$c, k' \geq 0, \tag{5}$$

where $V(a', k', 0, P)$ denotes the value of a country in the penalty phase with productivity shock a', capital stock k' and zero debt, Φ the capital adjustment costs, and γ the penalty parameter capturing the drop in TFP.

If it repays, the country enjoys the access to financial markets today and remains in the normal phase next period. Given the country-specific bond price schedule $q(s, b')$, country s chooses consumption c, next period's capital stock k', and bond holdings b' to maximize the repayment welfare given by

$$W^R(s) = \max_{c,k',b'} u(c) + \beta \sum_{a'|a} \pi(a'|a) V(s', N) \tag{6}$$

[5] The output and trade losses after sovereign default are well documented in the literature, though microfoundation for these evidence is not fully understood. Cohen (1992)[9] documents an "unexplained" productivity slowdown in the 1980s debt crisis. Tomz and Wright (2006)[32] reports that output is below trend about 1.4% during the entire period of renegotiation for a sample of 175 countries during 1820–2004. Rose (2005)[28] examines a sample of 150 countries over the recent half century and shows that defaulting countries experience an 8% annual decline in bilateral trade that lasts for 15 years. Agnostic about the channels of costs associated with default, we capture these losses as a drop in total factor productivities.

subject to

$$c + k' - (1-\delta)k + q(s,b')b' + \tau|b'| \leq ak^{\alpha} + b - \Phi(k',k), \tag{7}$$

and (5), where $\tau|b'|$ is the real resource cost of international borrowing and lending. The parameter τ controls the degree of financial integration in this economy. Infinitely large τ produces a world with closed economies; zero τ produces a world with no controls in international borrowing and lending.

For some countries with large amounts of debt relative to their income today, it is possible that given the set of available contracts, they cannot satisfy their budget constraints (7) together with non-negativity constraints (5). In such cases, countries have to choose to default on their debt. We label this *involuntary default*.

Country in the Penalty Phase

A country in the penalty phase suffers a drop in TFP each period, and so its production becomes $(1-\gamma)ak^{\alpha}$. It has no access to the international financial markets. Empirically, defaulting countries often regain access to markets after some period of exclusion. We thus assume that countries in the penalty phase have some exogenous probability λ of returning to the normal phase. Country $(a,k,0)$ in the penalty phase chooses consumption c and capital stock k' to maximize the utility given by

$$V(a,k,0,P) = \max_{c,k'} u(c) + \beta \sum_{a'|a} \pi(a'|a) \left[(1-\lambda)V(a',k',0,P) + \lambda V(a',k',0,N)\right] \tag{8}$$

subject to (4) and (5).

2.2 International Financial Intermediaries

International financial intermediaries are assumed to be able to commit to loan contracts. They are competitive, risk-neutral, and discount the future at the inverse of the risk-free interest rate $1/R$. They behave passively and are willing to finance any non-defaulting countries in the normal phase as long as they are compensated for the expected loss in case of default. The set of contracts is country-specific. For each country s, the bond price schedule $q(s,b')$ is such that for every b' the intermediaries break even

$$q(s,b') = \left[1 - p(s,b')\right]/R, \tag{9}$$

where $p(s,b')$ denotes the expected default probability of country s with bond holding b'. The default probability is the sum of the probabilities of the states under which country s

will choose to default on its debt b' next period. More specifically, the default probability is given by

$$p(s,b') = \sum_{a'|a} \pi(a'|a) d(a', k'(s,b'), b'), \tag{10}$$

where $k'(s,b')$ is the optimal capital stock that country s will choose if it decides to borrow b' this period and is the solution to the following problem

$$\max_{c,k'} u(c) + \beta \sum_{a'|a} \pi(a'|a) V(s', N), \tag{11}$$

subject to (5) and (7). Note that the bond price schedule specifies for any possible borrowing b', not just for the equilibrium borrowing.

2.3 Stationary Recursive Equilibrium

We first define the stationary distribution, then define the stationary recursive equilibrium, and finally provide some characterization of the equilibrium. Let μ be the probability measure on $(X, \aleph)$, where $\aleph$ is the Borel σ-algebra on X. For any $M \in \aleph$, $\mu(M)$ indicates the mass of countries whose states lie in M. Denote the transition matrix across states by $Q : X \times \aleph \to [0,1]$, where $Q(x, M)$ gives the probability of a country x switching to the set M next period.

Definition 1. The probability measure μ is *stationary* if

$$\mu(M) = \int_X Q(x, M) d\mu, \quad \text{for any } M \in \aleph. \tag{12}$$

Definition 2. A *stationary recursive equilibrium* consists of a world risk-free interest rate R, a bond price schedule $\{q(s,b')\}$, decision rules of countries $\{c(x), k'(x), b'(x), d(s)\}$, value functions of countries $\{V(x), W^D(a,k), W^R(s)\}$ and a distribution over countries μ, such that,

- Given $q(s,b')$, the decision rules and the value functions solve each country's problem.
- Given R and the decision rules, the bond price schedule makes financial intermediaries break even in each contract.
- Bond markets clear: $\int_X q(x, b'(x)) b'(x) d\mu = 0$.
- The distribution μ is stationary.

The theoretical characterization of the equilibrium is limited under the general equilibrium model with production. Still, the following provides two theoretical propositions characterizing the equilibrium. We will present detailed numerical characterization of the equilibrium in the next section.

Proposition 1. *If a country in the normal phase defaults on bond holding b_2, it will default also on b_1 for any $b_1 < b_2$ fixing (a, k).*

Proposition 2. *A country with a debt-output ratio smaller than γ will never default.*

Detailed proofs of the above two propositions are presented in Technical Appendix 1. Proposition 1 simply states that when a country defaults on a small amount of debt, it will default for any larger amount of debt. The reason is that the defaulting welfare is independent of debt while the repayment welfare decreases with debt. Thus, for countries with shock a and capital stock k, there exists a cutoff level of debt, above which they will default.

Proposition 2 offers a sufficient condition for safe debt. Given that output drops by a fraction of γ after default, a country with a debt-output ratio less than γ will never default because the debt relief is less than the output drop and the country also loses access to future borrowing after default. Note that this condition is not necessary for safe debt. Countries with debt-output ratios larger than γ may also choose to repay with probability one, and thus the safe debt-output ratio is at least as large as γ.

3 Quantitative Analysis

In this section, we assess the model's implication of financial integration on international risk sharing quantitatively. First, we present evidence that financial integration increases substantially and empirical findings that international risk sharing shows little improvement. We then calibrate the model economy to set up the laboratory where we reduce the transaction cost to endogenously generate financial integration. Finally, we present and investigate the model's implication that the observed degree of financial integration leads to little increase in international risk sharing.

3.1 Data

The degree of financial integration has undoubtedly increased over time. The literature commonly uses two direct measures of financial integration. One is a restriction measure which offers a qualitative index of official capital controls on cross-border capital flows.[6] The restriction measure indicates more financial integration over time; a large number of countries have removed capital controls and deregulated financial markets (see Kose et al. 2003[26]). The other is an openness measure using actual cross-border capital flows across countries, in terms of either gross (or net) foreign flows or gross (or net) foreign positions. These statistics present the same picture: a dramatic increase in financial integration.

To quantify the degree of financial integration over time, we adopt the openness measure. More precisely, we measure the degree of financial integration at any period as the ratio of the world sum of absolute net debt positions and the world GDP (later referred as the *world debt-output ratio*). The net debt position is the difference between the debt asset position and the debt liability position, constructed by Lane and Milesi-Ferretti (2007)[21]. We use this measure of financial integration because it is the closest empirical counterpart to our model. Our sample consists of 21 OECD countries and 22 more-financially-integrated countries (referred also as emerging markets later)based on the classification in Kose et al. (2003)[26].[7] The world debt-output ratio more than doubles from 8% in 1970–1986 to 18% in 1987–2004.

Conventional wisdom suggests that countries should be able to share the idiosyncratic risk better in a more-financially-integrated world, which motivates a large empirical literature examining the degree of international risk sharing over recent decades. The prevalent empirical approach to measure the degree of risk sharing is to use a panel or cross-country regression of consumption growth rates on GDP growth rates.[8] We present the panel regression analysis for the less-integrated period and the more-integrated period with our sample countries.[9] Specifically, we examine the OLS regression of the form

$$\Delta \ln c_t^i - \Delta \ln \bar{c}_t = \beta_0 + \beta_1(\Delta \ln y_t^i - \Delta \ln \bar{y}_t) + u_t^i, \tag{13}$$

where c_t^i denotes real final consumption of country i at period t, y_t^i real GDP, $\bar{c}_t$ and $\bar{y}_t$ average real final consumption and average real GDP over the sample countries, and u_t^i the error term and $\Delta x_t = x_t - x_{t-1}$ for any variable x. All variables are in the per-capita US dollars

[6]Most restriction measures are constructed based on the IMF publication *Annual Report on Exchange Arrangements and Exchange Restrictions* (AREAER). See Edison, Klein, Ricci and Slok (2004)[12] for a thorough survey.

[7]See Data Appendix 1 for details.

[8]Cochrane (1991)[8] and Mace (1991)[23] use the regression analysis of individual consumption growth on individual income growth to study the extent of risk sharing across domestic agents. Lewis (1996)[22] introduces this regression analysis to the international setting and rejects perfect risk sharing across countries.

[9]All the conclusions are robust to alternative measures of risk sharing, e.g. consumption variability and cross-country regression. See Data Appendix 3 for details.

obtained from the World Bank's *World Development Indicators*. The degree of international risk sharing is measured by the regression coefficient β_1; the lower the regression coefficient, the better countries share risk. Note that perfect risk sharing, generated by the standard complete markets model, implies that consumption growth should not respond to individual income growth, i.e., β_1 should be zero.

Our findings are summarized in Table 1. First, the regression coefficient β_1 is significantly different from zero in both periods; it is 0.76 in the less-integrated period, and 0.84 in the more-integrated period, both significant at the 5% level. The null hypothesis of perfect international risk sharing are rejected in both periods, consistent with the consensus in the literature that international risk sharing is far from perfect.

Table 1: Measurement of Risk Sharing: Regression Coefficient β_1

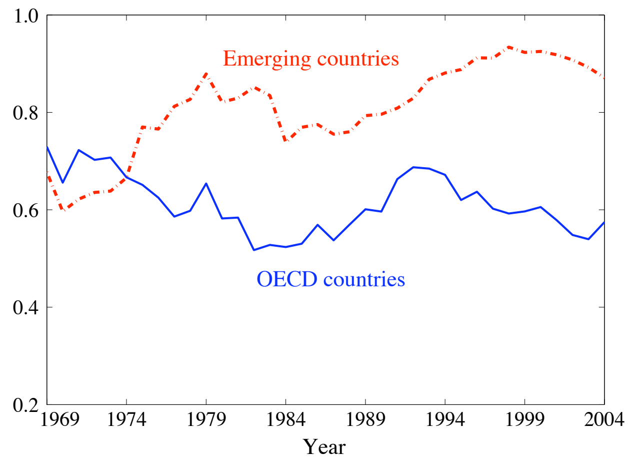
Sample	Less-Integrated Period 1970–1986	More-Integrated Period 1987–2004
43 countries	.76 (.03)	.84 (.02)
21 OECD	.62 (.04)	.60 (.03)
22 MFI	.79 (.05)	.88 (.02)

Note: numbers in parentheses are standard errors.

Second, international risk sharing shows no statistically significant improvement over the two periods; an F-test rejects the hypothesis that the regression coefficient β_1 is smaller in the more-integrated period. The result is robust to different sample groups of countries: emerging markets and industrial countries. Empirical studies on emerging markets all document little improvement or even a decline in risk sharing over the period of financial integration.[10] Thus, our result is consistent with the existing studies. Empirical studies on industrial countries document mixed results. Some studies argue that risk sharing improves after 1990 (e.g., Sorensen, Wu, Yosha and Zhu 2007[29]), while other studies have found little evidence of better risk sharing when looking at a longer period (e.g., Moser, Pointer, and Scharler 2004[25]). Figure 1 illustrates the reason for the different conclusions by plotting the 9-year rolling window panel regression coefficient for each year, as in Kose, Prasad and Terrones (2006)[18]. The regression coefficient becomes smaller after the 1990s for the OECD countries, which tends to lead to the conclusion that risk sharing increases. Nevertheless, the extent of risk sharing, even in 2000, is similar to that in 1970s. Thus, when comparing the two periods, we find it hard to argue that risk sharing improves substantially in the more-integrated period.

[10] See Kose, Prasad and Terrones (2006)[18] for a comprehensive review.

Figure 1: Regression Coefficient β_1 (9-Year Rolling Panel)



3.2 Calibration

In this subsection, we calibrate the model and set up the laboratory to explore the impact of financial integration on international risk sharing. To mimic financial integration, we first calibrate the transaction cost τ to match the observed world debt-output ratio in the less-integrated period. We then lower τ to match the world debt-output ratio in the more-integrated period. To isolate the impact of financial integration, the shock process and all other structural parameters are kept the same across the two periods.

We calibrate the world productivity process in two steps. We first compute the TFP series for each sample country, and then estimate a regime-switching process on the TFP series using maximum likelihood. The basic approach is similar to Bai and Zhang (2005)[4], but we need to incorporate the TFP drop parameter γ in the regime-switching process. According to our model, the computed TFP series of these countries over the exclusion period embody the drop in productivities. Thus, to infer the shock process we need to estimate the world TFP process joint with the TFP drop parameter.

Compute the TFP processes

The TFP series for country i at period t is computed using the standard growth accounting method:

$$\log A_t^i = \log Y_t^i - \alpha \log K_t^i - (1-\alpha)\log L_t^i,$$

where A_t^i denotes the TFP level, Y_t^i real GDP, K_t^i the capital stock and L_t^i employment. The capital stock is constructed perpetually using gross capital formation data (details see Data

Appendix 1). We detrend the TFP series using the average world TFP growth rate of 1.3 percent. Let a_t^i denote the logged and detrended TFP level.

Estimate World Productivity Process

Following Bai and Zhang (2005)[4], we use a stochastic regime-switching process to estimate the world productivity process. We assume that there are two regimes, $\Re \in \{1, 2\}$. Each regime $\Re$ has its own mean $\mu_\Re$, persistence $\rho_\Re$ and innovation standard deviation $\sigma_\Re$. The TFP shock a_t^i of country i in regime $\Re_t^i$ at period t follows a first-order autoregressive process given by

$$a_t^i = \mu_{\Re_t^i}(1 - \rho_{\Re_t^i}) + \rho_{\Re_t^i} a_{t-1}^i - \gamma h_t^i + \sigma_{\Re_t^i} \epsilon_t^i, \tag{14}$$

where ϵ_t^i is independently and identically distributed and drawn from a standard normal distribution $N(0, 1)$, and h_t^i is the dummy variable with 1 for the countries in the state of default and with 0 otherwise. At any period, country i has some probability of switching to another regime, governed by the transition matrix P.

Given the calibrated TFP panel series $\{a_t^i\}$ and the dummy panel series $\{h_t^i\}$, we use maximum likelihood to estimate the unknown parameters: $\Theta = \{(\mu_\Re, \rho_\Re, \sigma_\Re), P, \gamma\}$.[11] We use an extension of the technique in Hamilton (1991) from one time series to panel series. The Expectation-Maximization (EM) principle is used to compute the solutions.[12] Technical Appendix 2 describes the algorithm in detail.

The estimates of the parameter values are reported in Table 2. We label the two regimes according to their volatilities as the low-volatility and the high-volatility regime. The high-volatility regime can be interpreted as emerging countries, and the low-volatility regime as industrial countries. The TFP drop parameter is estimated to be 2%. This value is consistent with the standard literature value (see Aguiar and Gopinath (2006)[1]). In the numerical analysis, we discretize the shock space into 6 levels (3 points for each regime) following Tauchen (1986)[30]. The shock levels are chosen such that the simulated TFP series approximate the average statistics of the data TFP series in terms of autocorrelation and cross-section volatility.

[11] For data source see Data Appendix 2.

[12] See Dempster, Laird and Rubin (1977)[10] for details.

Table 2: Estimated Productivity Process

Regime	Innovation σ	Persistence ρ	Mean μ	Switching Prob. P	
				Low	High
Low-volatility	.02 (.001)	.997 (.004)	3.17 (.05)	.876 (.07)	.055 (.02)
High-volatility	.05 (.013)	.991 (.021)	4.39 (.10)	.124 (.27)	.945 (.19)
TFP drop parameter γ	.02 (.005)				

Note: numbers in parentheses are standard errors.

Calibrate Other Structural Parameters

All countries have the same parameter values. The period utility function takes the standard CRRA form of

$$u(c) = \frac{c^{1-\sigma} - 1}{1 - \sigma},$$

where the risk aversion parameter σ is chosen to be 2. We set the discount factor β to get the equilibrium risk free rate R at 1 percent per year in the first period.[13] The capital share α is set at 0.33 and the capital depreciation rate δ is set at 10% per year to match the U.S. equivalents. The capital adjustment cost takes the standard quadratic form of

$$\Phi(k', k) = \frac{\phi}{2} \left(\frac{k' - (1 - \delta)k}{k} \right)^2 k,$$

where ϕ is set at 3 to match the average ratio of investment volatility and output volatility across countries. We choose the probability of reentry to markets after default λ to be 0.20, following Gelos and Sahay (2004)[13]. They document that defaulting countries are denied access to markets for about 5 years on average.[14] We set the transaction cost parameter in each period to match the world debt-output ratio in each sample period: 8 percent and 19 percent, respectively. Table 3 summarizes all parameter values.

3.3 Simulation Results

After calibrating the model, we first use a non-linear recursive technique to compute the model equilibrium. For the detailed computational algorithm see Technical Appendix 3. We then simulate the model for the two periods and examine implications on international risk sharing. For each period, we simulate the model 1,000 times with 17 periods and 43 countries in each simulation, to be consistent with the data. Each simulation starts from the invariant

[13] The average real return on US Treasury Bills is about 1% per year over this period.

[14] Access is defined as public or publicly guaranteed bond issuances or public or publicly guaranteed borrowing through a private syndicated bank loan.

Table 3: Summary of Parameter Values

Preferences	Risk aversion	$\sigma = 2$
	Discount factor	$\beta = 0.85$
Technology	Capital share	$\alpha = 0.33$
	Depreciation	$\delta = 0.1$
	Capital adjustment cost	$\phi = 3$
Default penalty	Re-entry probability	$\lambda = 0.2$
	Output drop	$\gamma = 0.02$
Transaction cost	1970–1986	$\tau_1 = 6\%$
	1987–2004	$\tau_2 = 0$

stationary distribution of the corresponding period. The main findings are reported in Table 4.

When the transaction cost τ drops from 6% to 0% over the two periods, the world debt-output ratio rises from 8% to 18% by our calibration strategy. However, there is no improvement in international risk sharing; the panel regression coefficients are 0.66 and 0.65 in these two subperiods, respectively, and not statistically different from each other. Note that perfect risk sharing is clearly rejected in each period as in the data. The model generates the degree of risk sharing higher than that observed in the data in both periods. This is because our model abstracts from all other types of frictions and only looks at financial frictions. We find, however, that financial frictions are very important in accounting for the deviation from perfect risk sharing.

Table 4: Simulation Results

	Data		Model	
	1970–1986	1986–2004	$\tau_1 = 6\%$	$\tau_2 = 0\%$
World debt-output ratio	0.08	0.18	0.08	0.18
Regression coefficient β_1	0.76	0.84	0.66	0.65
	(.03)	(.02)	(.01)	(.01)

Note: numbers in parentheses are standard errors.

To understand the results, we first focus on the second period where the transaction cost is zero to illustrate how sovereign default risk impacts international risk sharing. Default risk endogenously constrains capital flows across countries, and borrowing is the most difficult at bad times. Default risk also gives rise to explicit sovereign defaults. These implications either hinder or hurt international risk sharing. We then look across the two periods to understand why there is no improvement in international risk sharing. We find that with sovereign default risk the degree of financial integration, generated by removal of the transaction cost, is too small to improve risk sharing. Moreover, more borrowing under a lower transaction cost leads to more equilibrium default, which hurts international risk sharing.

Default Risk and Imperfect Risk Sharing

To see the role of sovereign default risk, we contrast our benchmark model with default risk (labeled the *default model*) with a model without default risk, basically the incomplete markets model with the natural borrowing constraints (labeled the *no-default model*). The natural borrowing constraints are set such that countries at the maximum borrowing limits are able to repay their debt without incurring negative consumption. The roles of natural borrowing constraints are twofold. One is to guarantee the existence of equilibrium by ruling out the Ponzi scheme. The other is to capture the idea of perfect enforcement of debt contracts; countries will not default on their debt as long as it is physically feasible for them to repay.

Table 5 compares of the implications of the default model and the no-default model. Clearly the degree of risk sharing in the no-default model is not perfect with the regression coefficient of 0.45; incomplete markets cannot fully insure away country-specific idiosyncratic shocks. However, the no-default model provides much better risk sharing than the default model.

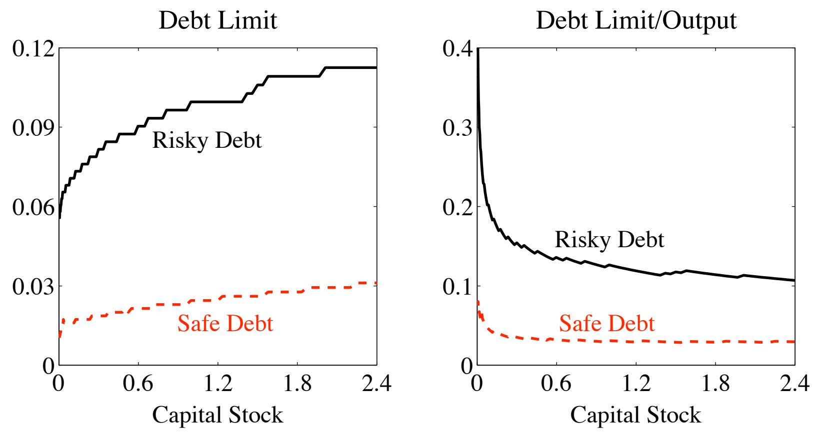
Table 5: Default vs. No-Default Model

	Default Model	No-Default Model
Regression coefficient β_1		
Full Sample	0.65 (.04)	0.45 (.03)
Defaulting countries	0.66 (.01)	–
Non-defaulting countries	0.62 (.01)	–
Maximum safe debt-output ratio	0.07	6.80
Maximum debt-output ratio	0.15	6.80
Equilibrium world debt-output ratio	0.18	1.21
Fraction of countries in the penalty phase	0.14	0.00

Note: numbers in parenthesis are standard errors.

Sovereign default risk affects international risk sharing through three channels. First, default risk endogenously constrains borrowing. As debt increases, countries first borrow risk free (referred to as *safe debt*), then have to pay a premium (referred to as *risky debt*), and finally reach their debt capacity. In Figure 2, the left panel plots the safe debt limit and the risky debt limit for countries with the median shock and zero debt, and the right panel illustrates these limits in terms of ratio to output. Richer countries (higher capital stocks) have larger borrowing capacities both in terms of safe debt and risky debt, but these borrowing capacities increase slower than output when capital stocks increase. The averages of the maximum safe and risky debt-output ratio are 7% and 15% across countries in the default model, much smaller than those in the no-default model, 680%.[15] This helps explain why the equilibrium world debt-output ratio in the no-default model is 6 times larger than that in the default model: 1.2 versus 0.18.

Figure 2: Endogenous Debt Constraints

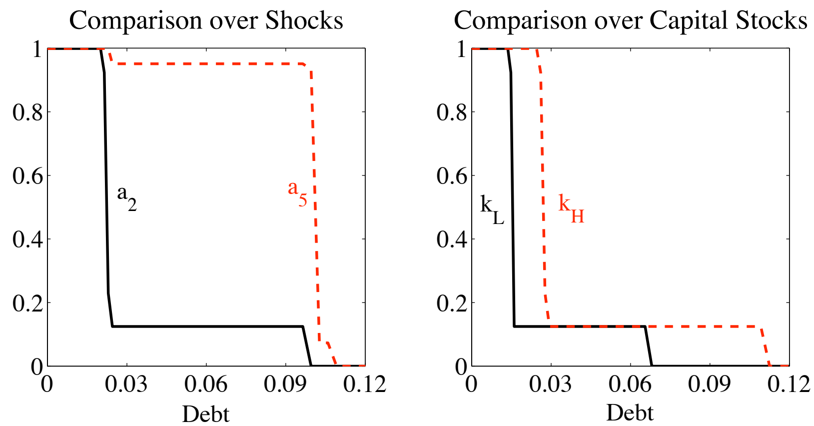


Second, borrowing is more difficult in bad times due to higher default risk. This is a common feature of the default model with incomplete markets as shown in Eaton and Gersovitz (1980)[11] and Arellano (2007)[2]. Because repayment is non-contingent and non-negotiable, it is more painful at bad times than at good times. Thus countries have higher incentives to default at bad times. Risk-neutral international financial intermediaries endogenize this pattern of default by charging higher interest rate premium at bad times. Figure 3 plots the bond price schedule, i.e., the inverse of the interest rates. The bond price decreases in loans with everything else fixed; it is $1/R$ for safe debt, lower than $1/R$ for risky debt, and zero for loans above the risky debt limit. Moreover, the bond price is lower for lower shocks (as illustrated in the left panel) and for smaller capital stocks (as illustrated in the right panel). These features show that default risk is high when output is low under low shocks and low capital stocks. Thus, sovereign default risk generates time-varying impediments to

[15] The maximum safe debt-output ratio and the maximum debt-output ratio are the average ratio of the natural borrowing limit and output.

international risk sharing; borrowing is the most costly when countries need it the most in bad times to smooth consumption.

Figure 3: Bond Price Schedule



The left panel plots the bond prices for countries with median capital and zero debt under different shock realizations. The right panel plots the bond prices for countries with the median shock and zero debt under different capital stocks.

Third, default risk gives rise to equilibrium default, which hurts risk sharing. Equilibrium default provides some state contingency in debt repayment; default usually occurs in bad times and so stopping servicing debt helps mitigate drops in current consumption. However, equilibrium default also hinders risk sharing in that defaulting countries are excluded from financial markets for a long random period. Since shocks are serially correlated, countries are likely to remain in bad times in this exclusion period and want to borrow, but they cannot. When we compare countries with a default history with those without a default history in our simulation, the first group has lower risk sharing than the second group; the regression coefficient β_1 is 0.66 for the first group and 0.62 for the second group.[16] Thus, actual default in fact hurts overall risk sharing. The default model generates 14% of countries in the state of default (see Table 5), which also contributes to the low degree of risk sharing.

Impact of Financial Integration

The above discussion illustrated how sovereign default risk prevents countries from risk sharing through constraints on borrowing, which is more difficult in bad times, and costly

[16] The F-test cannot reject the hypothesis that the regression coefficient for defaulters is larger than that for non-defaulters at the 5 percent significance level.

equilibrium default. These mechanisms are the inherent features of a world with default risk and incomplete markets, independent of the transaction cost. Now we compare the two periods to show why international risk sharing improves little when financial integration increases. Table 6 reports comparison of key statistics across the two periods.

Table 6: Model Implications across the Two Periods

	Less-Integrated Period $\tau = 6\%$	More-Integrated Period $\tau = 0$
	The default model	
World debt-output ratio	0.08	0.18
Maximum safe debt-output ratio	0.04	0.07
Maximum debt-output ratio	0.10	0.15
Interest rate premium	0.02	0.03
Newly defaulted rate	0.02	0.03
Fraction of countries in the penalty phase	0.10	0.14
Regression coefficient β_1	0.66 (0.01)	0.65 (0.01)
	The no-default model	
Equilibrium debt-output ratio	0.18	1.21
Regression coefficient β_1	0.56 (0.02)	0.45 (0.02)

Notes: numbers in parentheses are standard errors.

When the transaction costs are reduced from 6% to 0%, the financial markets become more attractive because international borrowing and lending are less costly. Countries have more incentive to repay their debt and remain in the market. The lenders endogenize these responses and allow more borrowing, in terms of both the safe debt and the risky debt. Over the two periods, the average maximum safe debt-output ratio increases from 4% to 7% and the average maximum debt-output ratio increases from 10% to 14%. Consequently, the equilibrium debt-output ratio also rises from 8% to 18% as in the data.

However, there is no significant improvement in international risk sharing. The key behind this result is again sovereign default risk. First, the default risk constrains the increase of capital flows across countries. To demonstrate this, we experiment the same reduction of the transaction cost in the no-default model and report the results in the lower panel of Table 6. In the no-default model, the world debt-output ratio increases by about six times from 18% to 121% and international risk sharing improves significantly. In contrast, the default model only leads to the doubling of the world debt-output ratio. This seemingly large increase in capital flows is too small to increase international risk sharing significantly.

Second, countries also do more risky borrowing under a lower transaction cost, which leads to more frequent sovereign defaults. This effect is illustrated by a higher average risk premium and a higher default rate in the more-integrated period, reported in Table 6. The average risk premium is 1% higher, and the newly defaulted rate is 1% higher in the more-integrated period.[17] Consequently, the fraction of countries in the penalty phase is also higher in the more-integrated period than that in the less-integrated period: 14% versus 10%. Our previous discussion shows that both the higher risk premiums and the actual defaults hurt the degree of risk sharing.

In summary, contrary to the conventional wisdom, we show that financial integration does not necessarily lead to increased risk sharing using our quantitative model. This helps reconcile why the extensive empirical studies find little evidence of better risk sharing in the more-integrated period. The numerical analysis also shows that the observed degree of financial integration seems large, but it is far smaller than the degree needed to increase risk sharing significantly. Thus, the commonly proposed policy—the removal of capital controls and deregulation of financial markets—cannot automatically deliver increased international risk sharing, if financial contracts are incomplete and imperfect enforced.

4 Further Analysis

In the quantitative section, we have demonstrated the impacts of sovereign default risk on financial integration and international risk sharing. Our model also generates rich predictions with regard to sovereign default. In this section, we first illustrate that these implications are broadly consistent with the data. We then provide sensitivity analysis on the no-default model and show that sovereign default risk is important in accounting for various dimensions of the data.

Model Implications on Sovereign Default

Our quantitative model has three important implications on sovereign default. First, the model produces a higher fraction of countries in the penalty phase in the more-integrated period. This is important in generating no significant increase in risk sharing because these countries cannot borrow and lend. For the data, we construct the fraction of countries in the penalty phase from the sovereign default episodes collected by Standard & Poor's. We classify a country as 'in the penalty phase' if it has not resumed its normal debt services and regained the access to markets after the event of default. The average number of countries in

[17] The newly defaulted rate is the fraction of countries in the normal phase that decide to default.

the penalty phase is 2.35 (about 5% of the 43 countries) in the less-integrated period and is 5.35 (about 9% of the 43 countries) in the more-integrated period. The fraction of countries in the penalty phase almost doubles over the two periods.[18] This empirical finding is robust to a large sample of countries. Using the data set constructed by Beers and Chambers (2003)[6] over 202 countries, the average fraction of countries in the penalty phase is 10% in the less-integrated period and 26% in the more-integrated period.

Second, the model predicts that countries without a default history have better risk sharing than countries with a default history. To test this prediction, we divide our sample into two groups: countries that never default and countries that have at least one episode of default. We measure the degree of risk sharing for each group using the panel regression analysis and report the empirical results in Table 7 together with those of the model. We find that in the data, countries with a default history have higher regression coefficients (and thus lower risk sharing) than countries without a default history over the full period and each sub-period. Thus, our model prediction is consistent with the data. Note that all the OECD countries are in the group of no-defaulters and the model explains a higher degree of international sharing for the OECD countries.

Table 7: Risk Sharing of Defaulters vs. Non-Defaulters

	Data		Model	
β_1	Defaulter	Non-Defaulter	Defaulter	Non-Defaulter
1970–2004	0.85 (.04)	0.64 (.02)	–	–
1970–1986	0.85 (.08)	0.65 (.03)	0.69 (.01)	0.63 (.01)
1987–2004	0.89 (.02)	0.79 (.04)	0.66 (.01)	0.62 (.01)

Note: numbers in parentheses are standard errors.

Third, the model predicts that all default episodes happen in the high-volatility regime associated with the low shocks. This is broadly consistent with the empirical findings. In the data all defaulting countries are emerging market economies after 1970. It is well documented that the TFP processes of emerging markets are much more volatile than those of OECD countries. In our sample, the median coefficient of variance of the TFP processes is 4.2% for the emerging markets, but only 1.2% for the OECD countries. Moreover, the model predicts that defaulting countries have a larger amount of debt than non-defaulting countries. For countries in the high-volatility regime, defaulters on average borrow 57% of their output, while non-defaulters only borrow 13% of their output. This is consistent with the finding in Reinhart, Rogoff, and Savastano (2003)[27]. They document that for a sample of 27

[18]See Data Appendix 2 for detailed documentation.

middle-income countries, defaulting countries on average borrow more in terms of output than non-defaulting countries: around 41% versus 34%.

No-Default Model

Finally, we conduct the sensitivity analysis on the no-default model. We calibrate the transaction cost in each period such that the no-default model generates the world debt-output ratio in the data. The transaction costs in both periods are much higher than those for the no-default model; τ is 7.5% in the less-integrated period and 6% in the more-integrated period. For the same transaction cost, eliminating sovereign default risk greatly increases capital flows, and thus a higher τ is needed to match the same flow. The panel regression coefficient β_1 is 0.58 with standard error 0.02 in the first period and 0.56 with standard error 0.02 in the more-integrated period. Thus, when the flows are match to the data in both periods, the no-default model generates little increase in risk sharing, but it also provides too much risk sharing relative to the data and the default model. Furthermore, the no-default model fails to match all the above features of sovereign default in the data.

5 Conclusion

Despite recent widespread deregulation and financial integration, extensive empirical studies find little evidence that countries have increased risk sharing; this is puzzling because conventional wisdom suggests that countries that are more financially integrated can better insure against risk. Our work shows financial integration does not necessarily lead to significant improvement in risk sharing if contracts are incomplete and enforceability of debt repayment is limited. Using a calibrated DSGE model with a continuum of countries and their default choices on sovereign debt, we demonstrate that the seemingly-large increase in capital flows is quantitatively too small to significantly improve risk sharing. In addition, financial integration leads to more sovereign defaults, which hurts risk sharing.

Limited enforceability on debt contracts has profound impacts on international capital flows and international risk sharing. Sovereign default risk endogenously constrains borrowing, makes borrowing more difficult in bad times, and generates costly equilibrium default. Thus, default risk is time-varying impediment to international risk sharing. The commonly proposed policy—the removal of capital controls and deregulation of financial markets—cannot automatically deliver improvement in international risk sharing, if financial contracts are incomplete and imperfectly enforced.

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Data Appendix

In this appendix, we first describe the data sources and the country coverage in detail, then show the empirical facts on sovereign defaults, and finally present different measures of international risk sharing.

1. Data Description

Country Sample

Given our interest in how financial integration affects risk sharing, we focus on countries with relatively open financial markets. Following Kose, Prasad, Rogoff, and Wei (2003)[26], we include 21 OECD countries and 22 more-financially-integrated countries in our sample. The 21 OECD countries are Australia, Austria, Belgium, Canada, Denmark, Finland, Germany, France, Greece, Ireland, Italy, Japan, the Netherlands, Norway, New Zealand, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. The 22 more-financially-integrated countries are Argentina, Brazil, Chile, China, Colombia, Egypt, Hong Kong, India, Indonesia, Israel, Korea, Malaysia, Mexico, Morocco, Pakistan, Peru, the Philippines, Portugal, Singapore, South Africa, Thailand, Turkey, and Venezuela.

Data Sources

The national account data (real GDP, real final consumption and real gross capital formation) are primely from the World Bank's publication *World Development Indicators* (WDI) 2004; for missing years in WDI, we use the Penn World Table 6.2. For the 21 OECD countries, employment data are from the OECD (various years) databases. For the following 13 countries, employment data are from national statistics: Chile, Colombia, Egypt, India, Israel, Korea, Malaysia, Pakistan, the Philippines, Singapore, Thailand, Turkey, and Venezuela. For the remaining 9 countries, employment data are supplemented by the Penn World Table. The data used to measure financial integration are from the data set constructed by Lane and Milesi-Ferretti (2007)[21]. All variables except employment are in terms of the U.S. dollar.

2. Sovereign Defaults over 1970–2004

In this appendix, we construct the overall statistics of the fraction of countries in default over the less-integrated and the more-integrated period. We collect the episodes of sovereign defaults on foreign-currency bank or bond debt.[19] According to Standard & Poor's, sovereign default is defined as "the failure to meet a principal or interest payment on the due date (or within the specified grace period) contained in the original terms of the debt issue". Beers and Chambers (2003)[6] report sovereign default episodes for 202 sovereign countries from 1975 to 2002 using data from Standard & Poor's. We expand the year coverage of their data set to 1970–2004 for our 43 sample countries. In particular, only Argentina defaulted in 2003, and there are no countries defaulting during 1970–74 and 2004.

The default episodes are summarized in Table 8. A country is classified as "in default" until its normal debt services resume after negotiation and it regains the access to markets. For example, Argentina defaulted in 1982 and is in default until 1993 according to Standard & Poor's. Using this table, we can construct the fraction of countries in default for each period. The average number of countries in default is 2.35 (about 5% of the 43 countries) in the less-integrated period and is 5.35 (about 9% of the 43 countries) in the more-integrated period.[20] The fraction of countries in default almost doubles over the two periods.

Table 8: Countries and Years in Default

Country	Years in Default
Argentina	1982–93, 2001–03
Brazil	1983–94
Chile	1983–90
Egypt	1984
Indonesia	1998–99, 2000, 2002
Mexico	1982–90
Morocco	1983, 86–90
Pakistan	1998–99
Peru	1976, 78, 80, 84–97
Philippines	1983–92
South Africa	1985–87, 89, 93
Turkey	1978–79, 82
Venezuela	1983–88, 90, 95–97

3. Alternative Measurement of Risk Sharing

This appendix presents two popular ways of measuring international risk sharing in the literature. One uses the cross-section regression analysis. The other uses consumption

[19] Government defaults on domestic-currency debt are rare.

[20] Using the data set constructed by Beers and Chambers (2003)[6] over 202 countries, the average fraction of countries in default is 10% in 1973–86 and 26% in 1987–2002. Thus, the bigger country sample also indicates that the fraction of countries in default increases dramatically in the more-integrated period.

volatility relative to output volatility. Both methods indicate no substantial increase in international risk sharing in the more-integrated period relative to the less-integrated period.

Cross-Section Regression

One alternative way to estimate the degree of risk sharing is to use cross-section regression, proposed by Cochrane (1991)[8]. For each year, we run the same regression as specified in equation (13). Table 9 shows the median of the cross-section regression coefficients β_1 in the less-integrated period and the more-integrated period. Again, international risk sharing is far from perfect for each period and each country group. More important, there is no significant increase in international risk sharing for both groups of countries over the two periods.

Table 9: Median Regression Coefficient on Output Growth β_1

Country Group	Less-Integrated Period 1970–1986	More-Integrated Period 1987–2004
43 countries	.75 (.12)	.86 (.07)
21 OECD	.59 (.16)	.62 (.12)
22 MFI	.74 (.17)	.87 (.11)

Notes: numbers in parentheses are standard errors.

Consumption Volatility

Besides the regression-based measurements of international risk sharing, another commonly used measurement is the ratio of consumption volatility and GDP volatility, as in Backus, Kehoe and Kydland (1992)[3]. With more financial integration, countries should have lower consumption volatility relative to output since countries can insure better their idiosyncratic shocks. Table 10 reports the average ratio of consumption volatility and GDP volatility across different groups of countries over the two periods. There is no statistically significant decrease in the relative consumption volatility over the two periods.

Technical Appendix

1. Characterization of Equilibrium

Proof of Proposition 1: Since country (a, k, b_2, N) chooses to default, we have

$$V(a, k, b_2, N) = W^D(a, k) > W^R(a, k, b_2).$$

Table 10: Mean Ratio of Consumption Volatility and Output Volatility

Country Group	Less-Integrated Period 1970–1986	More-Integrated Period 1987–2004
43 countries	1.08 (.29)	0.92 (.17)
21 OECD	1.07 (.23)	0.88 (.16)
22 MFI	1.10 (.35)	0.95 (.17)

Notes: numbers in parentheses are standard errors.

Since the repaying welfare W^R is increasing in b, we have

$$W^R(a,k,b_2) > W^R(a,k,b_1) \text{ for any } b_1 < b_2.$$

This implies $W^D(a,k) > W^R(a,k,b_1)$ for any $b_1 < b_2$. Thus, country (a,k,b_1,N) will also choose to default. Q.E.D.

Proof of Proposition 2: For any country (a,k,b,N) with $b > -\gamma a k^\alpha$, the budget set under repayment is larger than that under default. This implies that the optimal allocation of $W^D(a,k)$ is feasible under $W^R(a,k,b)$. Let (c_r, k'_r, b'_r) and $(c_d, k'_d, 0)$ denote the optimal choices of the recursive problems W^R and W^D respectively. Thus, we have

$$\begin{aligned} W^R(a,k,b) &= u(c_r) + \beta \sum \pi(a'|a) V(a', k'_r, b'_r, N) \\ &\geq u(c_d) + \beta \sum \pi(a'|a) V(a', k'_d, 0, N). \end{aligned}$$

Furthermore, we know that the repaying welfare is higher than the defaulting welfare when $b \geq 0$, and in particular, $V(a,k,0,N) \geq V(a,k,0,P)$. Therefore, we have

$$W^R(a,k,b) \geq u(c_d) + \beta \sum \pi(a'|a) V(a', k'_d, 0, P) = W^D(a,k).$$

Hence, any country with $b > -\gamma a k^\alpha$ will not default. Q.E.D.

2. Estimation of the World Productivity Process

This appendix describes the EM algorithm, used to obtain the maximum likelihood estimates of parameters in the regime-switching process (14). This is an extension of Hamilton (1989)[15]. The log-likelihood function is given by

$$L(\Psi;\Theta) = \sum_{i=1}^{N} \log\left(f(\Psi^i;\Theta)\right),$$

where $\Psi^i = \{a_T^i, a_{T-1}^i, ..., a_1^i\}$ denotes country i's TFP series, $\Theta = \{\{\mu_\Re, \rho_\Re, \sigma_\Re\}_{\Re=1,2}, \gamma, P\}$ the set of the parameters to be estimated, N the number of countries, T the total number of periods, $\Re$ the regime and f the density function given by

$$f(\Psi^i; \Theta) = \sum_{\Re^i} f(a_T^i | \Re_T^i, a_{T-1}^i; \Theta) \cdots f(a_2^i | \Re_2^i, a_1^i; \Theta) p(\Re_T^i | \Re_{T-1}^i) \cdots p(\Re_2^i | \Re_1^i) p(\Re_1^i).$$

Due to the nonlinearity of the maximum likelihood function, we cannot solve the parameters analytically. Instead, we use the EM algorithm to solve the maximum likelihood estimates iteratively. We start with an initial guess of the parameters Θ_{n-1}. We then update the conditional probabilities of regimes in each period for each country using Bayes' rule. Given the conditional probabilities, we next compute Θ_n with maximum likelihood. We iterate these procedures until $\{\Theta_n\}$ converges.

Following Hamilton (1996), we compute the standard errors of the estimated parameters as follows:

$$\phi_{OP} = \frac{1}{T \times N} \sum_{i=1}^{N} \sum_{t=1}^{T} \left[h_t^i(\hat{\Theta}) h_t^i(\hat{\Theta})' \right],$$

where h_t^i denotes the score given by

$$h_t^i(\Theta) \equiv \frac{\partial \log f(a_t^i | \Psi_i; \Theta)}{\partial \Theta}.$$

3. Solution Algorithm

To compute the model, we start with a guess of the world interest rate R and a bond price schedule $q(s, b')$ as the reciprocal of R for each country s with loan demand b'. We then solve each country's value function and decision rules under both the normal and penalty phase using value function iteration. Given the value function under the normal phase, we can compute the optimal capital stock $k'(s, b')$ for country s with the intention of borrowing b'. The bond price schedule is then updated as $q^{n+1}(s, b') = (1 - p^n(s, b'))/R$, where $p^n(s, b')$ is the default probability constructed from the optimal default choices and $k'(s, b')$. We iterate the above procedures until q converges, i.e., $|q^{n+1}(s, b') - q^n(s, b')| < \epsilon$.

Given the converged bond price schedule, we next compute the invariant distribution μ^*, which is the solution to $\mu^* = \mu^* Q$, where Q denotes the transition matrix over states governed by the optimal decision rules. Finally, we calculate the excess demand of bonds over the invariant distribution and check if the bond markets clear. If not, we update the interest rate and repeat the above procedure.