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Joseph E. Stiglitz, *Columbia University*

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Abstract

Advocates of capital market liberalization argue that it leads to greater stability: countries faced with a negative shock borrow from the rest of the world, allowing cross-country smoothing. There is considerable evidence against this conclusion. This paper explores one reason: integration can exacerbate contagion; a failure in one country can more easily spread to others. It derives conditions under which such adverse effects overwhelm the putative positive effects. It explains how capital controls can be welfare enhancing, reducing the risk of adverse effects from contagion. This paper presents an analytic framework within which we can begin to address broader questions of optimal economic architectures.

KEYWORDS: contagion, liberalization, globalization, capital markets, financial crisis

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Advocates of capital market liberalization have long argued that it would lead to greater stability. Countries that are integrated into the global financial system could, if they faced a negative shock, borrow from the rest of the world. This would allow cross-country smoothing (Stiglitz 2000).

There is, by now, considerable evidence against this conclusion. (See Kose *et al.* 2003.) Indeed, the IMF seemed surprised when the empirical evidence contradicted this theoretical proposition. (See Kose *et al.* 2006). But they should not have been. It should have been evident that developing countries that liberalized have been more subject to crises and volatility. (See Ocampo *et al.,* 2008).

One reason for these adverse outcomes is that capital flows have not behaved in the way that was hypothesized. Capital flows to and from developing countries are often pro-cyclical. Given this, it would have been difficult to see how capital market liberalization could have reduced variability.

One explanation of these procyclical capital flows is that "bankers don't like to lend to those who need the money." Adverse shocks induce them to reduce their lending.

There are other possible explanations for why liberalization would be associated with an increase in, say, the volatility of consumption and the lowering of expected utility. For instance, Stiglitz (2008) has developed a life cycle model in which, without capital market liberalization, positive productivity shocks lead to intertemporal smoothing; individuals save more, thus increasing wages of future generations. In effect, the benefits of a productivity shock at time t are shared with future generations. Capital market liberalization, then, may result in greater volatility in consumption, as the generation in which the positive productivity shock occurs gets to reap the full benefits for itself.

This paper explores a third set of explanations for the adverse consequences of capital market liberalization, illustrated by global financial crises, such as those that occurred in 1998 and 2008. A failure in one or more countries can quickly spread elsewhere. Since the adverse effects of a downturn can be great, it raises the question: can these periodic but highly negative effects overwhelm the putative positive effects of income smoothing?

The existence of these adverse effects was itself a puzzle—at least within the standard models that had assumed that by sharing risks, the effect of any shock would be mitigated. Indeed, the notion that risk sharing would lead to a more stable global financial system was one of the reasons that certain regulators believed we were in a new era of the "Great Moderation." For the first time, risk was so widely shared that the world could undertake more risk, growing more rapidly *and* more stably. Needless to say, things haven't turned out the way that was anticipated.

There are, in turn, two possible explanations for why risk diversification didn't work in the way that many had hoped. The first is that the financial institutions didn't understand the risks that they confronted and/or that their deceptive accounting practices, designed to mislead regulators, investors, and the tax collector alike, also deceived themselves. The result was that they held on to many of the toxic mortgages; risk was not in fact diversified and spread out.

There is a second explanation, and that is that the central models employed by macro- and financial economists were fundamentally flawed.[1] They *assume* a structure that says that if risk is widely diversified, the system will be more stable and expected utility will be higher.

Curiously, the advocates of liberalization have never fully believed this. For they have always worried about the risk of contagion *once a crisis starts.* But, as we have noted, most of the mechanisms by which contagion occurs are associated with financial market interlinkages.[2] This implies that there is a cost associated with greater financial or capital market integration—the risk that a problem in one country will lead to problems elsewhere. Even without, say, financial market interlinkages, there can be extensive interdependencies through which a shock in one part of the system can be transmitted to others. Any bank making a real estate loan would have been affected by the breaking of the real estate bubble. But financial market interlinkages can exacerbate the contagion of problems from one economic unit to another.

The word "contagion" itself is associated with the transmission of diseases; and the traditional way of reacting to worries about contagion is "quarantining," that is, breaking the links between the diseased individual and the rest of society. The more integrated a society, the more rapidly can diseases spread.

A coherent analysis of the desirability of financial and capital market liberalization should, accordingly, take into account the benefits of risk sharing when things work well—and the costs through contagion, when things don't. Remarkably, most of the literature has not done so, treating the benefits of integration and the management of the risks of contagion as if they were separable.

A moment's reflection suggests one of the reasons that standard models have gone astray: they make strong mathematical assumptions under which risk sharing is always desirable. With convex technologies and concave utility

[1] The first explanation focuses on a different flaw in the standard model employed by macro- and financial economists—the assumption of rationality. Obviously, if the banks had been fully rational—in the way that term is usually used-- they would not have retained so much of the risk.

[2] There are other mechanisms, e.g. trade, but these work more slowly and are more muted; if trade were the only mechanism for contagion, IMF intervention in the East Asia crisis would have taken on a markedly different form.

functions, risk sharing is always beneficial. Thus, the more globally integrated the world economy, the better are risks "dispersed." But if technologies are not convex, then risk sharing can lower expected utility. While simplistic models typically employed in economics *assume* convexity, the world is rife with non-convexities. Information structures and externalities themselves give rise to a natural set of convexities.[3] Learning processes (e.g. associated with learning by doing) and R&D are naturally associated with non-convex technologies. Bankruptcy, too, introduces a key non-convexity, as do the constraints associated with information imperfections (moral hazard and adverse selection)[4,5]. The credit market imperfections (in part arising from information imperfections) in turn give rise to the financial accelerator, which in turn implies that the effect of a shock can be *amplified*.[6] Concerns about bankruptcy can also give rise to a process of *trend reinforcement* (Battiston, *et al.* 2009). For instance, a firm experiencing a negative shock— pushing it closer to the bankruptcy brink—will have to pay higher interest rates, implying that the likelihood of a further decline in net worth has increased. Similarly, liquidity crises are associated with "forced" sales of assets, leading to price declines, adversely affecting any bank lending on the basis of collateral. But the declining value of assets induces a reduction in asset-based lending, with consequent macroeconomic effects (Miller and Stiglitz, forthcoming).

The natural models of contagion illustrate the role of non-convexities. Assume a proportion of the population p has a disease, and that an infected person communicates the disease with probability z to any non-infected person he comes into contact with. Assume the degree of integration of the society is measured by 1/g, which measures how long it takes him to "bump into" another person, chosen

[3] Information/knowledge can be viewed as a "fixed cost"—the greater the scale of production, the greater the saving from a cost saving idea. Radner and Stiglitz (1984) describe a natural non-convexity that arises in the "quantification" of information. Starrett (1972) describes a natural non-convexity associated with externalities.

[4] See, for instance, Arnott and Stiglitz (1988).

[5] Credit market imperfections play a key role in the instability associated with financial market integration on the part of developing countries. As we have noted, credit flows are pro-cyclical, in contrast with the pattern predicted by "standard" theory, which suggests that they should be countercyclical.

[6]See also Greenwald, Stiglitz, and Weiss (1984), who show that information imperfections can give rise to equity rationing. Greenwald and Stiglitz (1993) showed how this could led to a financial accelerator: If firms' production or demand is limited by their access to capital, the effect of a positive shock that increases equity is amplified as, say, investment increases by a multiple of that amount, and then multiplied further through the usual multiplier (Bernanke and Gertler 1995). There is a growing literature on how these credit and collateral constraints can give rise to bubbles and economic fluctuations. See Kiyotaki and Moore (1997), Gellegati and Stiglitz (1992), and Miller and Stiglitz (forthcoming).

randomly from the population. Then the spread of the diseases is given by dp/dt = gpz(1 – p), a logistic curve.

In any of these circumstances, risk sharing (closer integration) can be welfare-decreasing. A simple example illustrates. Consider a case where a firm is near bankruptcy, so it has to pay high interest rates—higher than the mean return on its assets. If there is no risk (its returns are certain), then the death of the firm is inevitable. But if there is some variability in returns, then there is a chance that it will break out of the death trap. There is some chance that it will have a very positive return that will result in interest rates falling enough that the mean return is now in excess of the interest rate it has to pay.

Those concerned with designing electric networks have worried about analogous problems posed by connectivity. Developing a strong integrated electric grid, it was believed, would have distinct benefits. An increase in demand in one part of the grid could be "smoothed" with other parts of the grid. The system excess capacity required to prevent a brownout or blackout from occurring (with greater than a particular frequency) was thereby greatly reduced; alternatively, for any given capacity, the probability of a brownout or blackout was reduced. But a large surge in demand, or a failure in one part of the system, could lead to system-wide failure; in the absence of integration, the failure would have been geographically constrained. The U.S. learned this lesson bitterly in August 2003, when a minor problem with a high-voltage power line in northern Ohio launched a series of failures that became the biggest blackout in North American history, leaving 50 million without electricity (Minkel 2008).

Well designed networks have circuit breakers, to prevent the "contagion" of the failure of one part of the system to others. Yet, advocates of unbridled liberalization have paid little attention to these risks; there has been virtually no discussion of circuit breakers, and indeed, in some quarters, such circuit breakers—such as the temporary imposition of capital controls—have been vehemently opposed.[7]

This paper presents a simple analytic framework within which we can begin to address the question of how economic architecture—the structure of economic relationships—affects systemic performance. We focus on risk sharing (capital flows), ignoring other channels through which shocks to one country might affect those with which it is interconnected.[8] We structure the model to

[7] Interestingly, in the aftermath of the equity market crash of 1987, circuit breakers were imposed in those markets. Following the flash crash of May 6, 2010 in America's financial markets, these have been expanded, and there are ongoing proposals for further strengthening.

[8] An earlier paper (Stiglitz 2010) sets this problem within a broader context, showing more general conditions under which liberalization (trade and capital market integration) lowers expected utility as a result of increased *general equilibrium* risk. It makes the point that much of our belief in the virtues of liberalization is based on either partial equilibrium models or on first best general equilibrium models.

give the benefit of the doubt to liberalization: in our model, without system failure, liberalization is always desirable, i.e. capital flows are income-smoothing (in contrast to the real world, or more general theoretical models, where they often increase variability). Yet we show that with a risk of system failure, it is possible that, in general, full integration is not desirable.

The paper proceeds as follows. After setting up the general framework in section II, we derive conditions under which liberalization is welfare-enhancing, showing in particular that full liberalization/integration is not optimal. Section III focuses on the special problems posed by system failure. Section IV then shows that circuit breakers (which can be interpreted as capital controls invoked under certain circumstances) can be welfare-enhancing. Section V then poses the question of the optimal design of networks. Section VI explores in detail a particular parameterization, where there is no production enhancement from diversification (output is linear in inputs), but there are bankruptcy costs.

A central message of the paper is that with non-convexities, risk diversification can be welfare-decreasing. Section VII shows that such non-convexities can arise in the long run even when they seemingly do not make their appearance in the short run. Section VIII provides an intuitive interpretation of the results, while sections IX and X relate our results to the broader literature on contagion and systemic risk, especially in financial markets. We conclude with some general observations about the direction of future research.

II. A simple model without system failure

We assume that output in country *i* is a function of a random variable, S_i, which (with a shift in origin)[9] can be thought of as the stock of available capital. (In Section X we provide a broader interpretation of our model, focusing on financial capital.)

$$Q_i = F(S_i), \quad F' > 0, \quad F'' \leq 0$$

In autarky,

$$S_i = \hat{S} + \epsilon_i$$

where $S_i = \hat{S} + \epsilon_i$

[9] That is, we allow negative S.

Where ε are a set of i.i.d. shocks, E (ε) = 0 and Var (ε) = σ^2. We normalize by choosing our units so that $\hat{S} = 1$. This means that if there are N countries, expected global output is

$$NEF(\hat{S} + \epsilon_i) \approx NF(\hat{S}) + \frac{1}{2}NF''(\hat{S})\sigma^2 = NF(\hat{S})\left(1 - \frac{bs^2}{2}\right)$$

where

$$s^2 = \frac{\sigma^2}{\hat{S}^2}$$

$$b = -F''(\hat{S})\hat{S}^2/F(\hat{S})$$

Average output per country is

$$EQ \approx \bar{Q} \equiv F(\hat{S})\left(1 - \frac{bs^2}{2}\right)$$

With liberalization, there is smoothing. Capital flows to where there is a shortage. Assume that the intertemporal discount factor is unity and that there is full smoothing, i.e.

$$S'_i = \sum S_i /N \ = \hat{S} + \sum \epsilon_i /N$$

It follows that

$$NEQ = NEF(\hat{S} + \sum \epsilon_i /N) > NEF(\hat{S} + \epsilon_i)$$

so long as F" < 0 and $\sigma^2 > 0$.

It is easy to calculate the benefits of liberalization.

$$NEF(\hat{S} + \sum \epsilon_i /N) \approx NF(\hat{S})\left(1 - \frac{bs^2}{2N^2}\right)$$

so

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$$\Delta NQ \approx NF(\hat{S})\frac{bs^2}{2}\left(1-\frac{1}{N^2}\right)$$

i.e. the change in average output

$$\Delta\bar{Q} = F(\hat{S})\frac{bs^2}{2}\left(1-\frac{1}{N^2}\right)$$

and

$$\lim_{N\to\infty}\Delta\bar{Q} = F(\hat{S})\frac{bs^2}{2}$$

Liberalization allows for smoothing. With i.i.d. shocks, in the limiting case there is full smoothing, so that the benefit of liberalization is the expected loss of output from the variability of shocks across countries. This is a simplified variant of the standard argument for liberalization.

III. Liberalization with failure

We now consider a simple model of systemic failure, which we can think of as

System failure: $\epsilon_i = -\infty$

With this definition, a system failure in any one country leads to a system failure in all countries under liberalization. We define

$\underline{Q} = Q(S)$ for $S \leq S^* < 1$.

S^* can be thought of as the level of S below which the country (firm) goes into bankruptcy. At this point, losses are limited. The difference between $\lim_{S\to S^{*+}} F(S)$ and $\underline{Q}$ can be thought of as the bankruptcy costs, in the case of a firm, or the costs of societal disruption associated with "crisis," in the case of a country. This means, of course, that Q(S) is no longer concave, so the presumption that risk pooling will be welfare enhancing no longer obtains.

Assume that the probability of failure of any country is 1 – p, and assume for the moment that p is fixed. Then in the absence of liberalization

$$ENQ = pNEF(\hat{S} + \epsilon_i) + N(1-p)\underline{Q} \approx pNF(\hat{S})\left(1 - \frac{bs^2}{2}\right) + N(1-p)\underline{Q}$$

With full liberalization, the probability of international system failure is

$$q(N) = 1 - p^N$$

so that expected output is

$$NEF\left(\hat{S} + \sum \epsilon_i / N\right) p^N + (1 - p^N)\underline{Q}N$$

Thus, liberalization is desirable if and only if

$$pEF(\hat{S} + \epsilon_i) < EF\left(\hat{S} + \sum \epsilon_i / N\right) p^N + (p - p^N)\underline{Q}$$

Or

$$p^{N-1} > \frac{EF(\hat{S} + \epsilon_i) - \underline{Q}}{EF(\hat{S} + \sum \epsilon_i / N) - \underline{Q}}$$

Without loss of generality, we can set $\underline{Q} = 0$.[10] It immediately follows that if p is fixed and bound away from zero, the probability of *system-wide* failure goes to one as N goes to infinity, and hence system wide output goes to the lower bound, zero: *liberalization is never desirable.*

In the case where p is not bound away from zero, the calculations are more difficult. We can approximate the RHS by

$$\left(1 - \frac{bs^2}{2N^2}\right)\left(1 - \frac{bs^2}{2}\right)$$

[10] In this formulation, if S* > 0, the immediate drop to zero from F(S*) > 0 can be thought of as the bankruptcy cost. If S* = 0, the production function, with bankruptcy, is convex; if S* > 0, it is neither convex nor concave. Later sections explore some of the complications that this introduces.

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We focus on the case where variance is small, i.e. $s^2 < 2/b$.[11] The condition for liberalization being desirable can be written

$$p > \left[\left(1 - \frac{bs^2}{2N^2}\right)\left(1 - \frac{bs^2}{2}\right)\right]^{\frac{1}{N-1}}$$

For each N, there is a critical probability of failure above which liberalization is undesirable. The critical value of N, for each p, is given by the solution to

$$p^* = \left[\left(1 - \frac{bs^2}{2N^2}\right)\left(1 - \frac{bs^2}{2}\right)\right]^{\frac{1}{N-1}}$$

with

$$\frac{d\ln p^*}{d\ln N} = -\frac{N}{N-1}\left(\ln p^* + \frac{2bs^2/N^3}{2 - \frac{bs^2}{N^2}}\right) > 0$$

Even if the probability of failure goes to zero as the number of countries goes to infinity, liberalization may not be desirable. Assume p = p(N) such that $\lim p^N = \alpha$.[12] $1 - \alpha$ is the probability of system failure. Then liberalization is desirable if and only if, in the limit,

$$EF(\hat{S} + \epsilon_i) < EF\left(\hat{S} + \sum \epsilon_i / N\right)\alpha$$

i.e.

$$\alpha > \frac{F(\hat{S} + \epsilon_i)}{F(\hat{S})} \approx 1 - \frac{bs^2}{2}$$

This equation identifies the three critical parameters that determine whether liberalization is desirable: (a) the higher the probability of failure, the less desirable liberalization; (b) the higher the variability, the greater the benefit

[11] In the high variance case, the above expression is always negative for large enough N, so that, for large enough N, liberalization is always desirable.
[12] $\lim \ln p^N = \lim N \ln p = \lim \ln p/1/N$. If p (<1) is fixed, then the limit is minus infinity. But if p goes to one, then both the numerator and the denominator go to zero. The limit then equals $\lim -N^2 p'/p$.

of liberalization; and (c) the higher the cost of variability, the greater the benefit of liberalization.

An alternative formulation

There is a slight modification of this formulation[13] that enables a simplification of the calculation. Assume the country is faced by two shocks, the relatively small i.i.d. ε's described earlier and a large shock, large enough to cause systemic failure, a macro-shock that occurs in only one country, and it occurs in that country with probability Π/n, where n is the number of countries.[14] As before, we follow the normalizations that when bankruptcy occurs, Q = 0, and $\hat{S} = 1$. For simplicity, in this section, we assume that the support of ε is sufficiently narrow that in the absence of the macroeconomic shock, the country never goes bankrupt. We know the utility of final consumption by U(Q) with U" < 0, i.e. there is risk aversion.

Without integration,

$$EU_{NI} = (1 - \Pi/N)\ EU(F(1 + \varepsilon)) + (\Pi/N)\ U(0)$$

With integration among N countries,

$$EU_{N(n)} = (1 - n\,\Pi/N)\ EU(F(1 + \Sigma\varepsilon/n)) + (n\Pi/N)\ U(0).$$

The first term represents the benefit from risk diversification (the one usually discussed within the literature advocating capital market integration), the second is the increased risk of contagion. As n increases, there are diminishing returns to diversification, while the costs of contagion—the potential loss from being integration with a failed economy—increases:

$$d\,EU_{N(n)}/dn = (1 - n\,\Pi/N)\ \partial\, EU(F(1 + \Sigma\,\varepsilon/n))/\partial n\ - (\Pi/N)[\ EU(F(1 + \Sigma\varepsilon/n)) - U(0)]$$

[13] Suggested by an anonymous referee.
[14] Similar results obtain if, as in the previous formulation, the probability of a large shock hitting each country is independent. The only difference is that in this last case, as the number of countries that are integrated increases, the probability that at least one of them faces a macro-economic shock increases more rapidly than in this model, so the optimal size of the risk-sharing "club" is smaller.

Standard arguments for risk diversification explain why $EU(F(1 + \Sigma\, \varepsilon/n)$ increases as n increases. Setting

$$d\, EU_{N(n)}/dn = 0$$

there is an optimal size risk sharing club (see the discussion below in section V). In the limit, as the variance of ε goes so zero, as the concavity of F goes to zero and risk aversion goes to zero, there are no risk benefits for sharing, and only contagion costs, so $n^* = 1$. Since the marginal benefits to risk diversification diminish to zero, while as n gets large, $EU(F(1 + \Sigma\varepsilon/n)) - U(0) \approx U(F(1)) - U(0)$ is a large, finite number, *full integration is never desirable.*

Risk sharing ex post

There are many ways of sharing risk, in particular, before or after production. For instance, countries could provide a consumption sharing agreement without capital market liberalization, i.e. a capital sharing agreement. They would then not be exposed to the risk of systemic failure, but enjoy the benefits of risk diversification. They would lose the benefits associated with pro-production risk sharing due to the concavity of the production function. Thus, a full consumption risk sharing agreement with no production sharing among n countries would generate expected utility of

$$EU^R{}_n = E\, U\{ [(n - \psi(n)\, \Sigma F(1 + \varepsilon))]/n\}$$

where ψ(n) is the probability distribution of the number of countries in the "club" of n members that face a systemic risk. In the simple model described earlier, where only one country faces a macroeconomic shock, then $\psi = \{1$ with probability n/N, 0 with probability $1 - n/N\}$. Because there are no contagion effect, optimal consumption risk sharing involves all N countries.

We can combine production and consumption risk sharing. The fact that because production and consumption risk sharing are partial substitutes, the benefits of production risk sharing (diversification) are reduced, while the costs of contagion remain essentially unabated, implies that the optimal size of production sharing arrangements will be smaller, and indeed, when the loss from contagion is high enough and the benefits of production smoothing low enough, then there will be no production smoothing.

IV. Circuit breakers

Assume that we construct a system of circuit breakers (e.g. restrictions on capital flows). Circuit breakers can be either simple or complex; they can, for instance, specify limits on capital flows from one country to another that depend only on the sending country, or that depend on the circumstances in both countries. Consider the case of two countries. Then it is optimal to share risk so long as $\Sigma S_i > 2S^*$. But if $\Sigma S_i < 2S^*$, then it is better to have only one country go bankrupt, rather than both, and there should be no transfer of resources from the better-off country to the poorer country. (Indeed, given our assumptions, expected utility would be even higher if the poorer country transferred income to the richer.) In a world with many countries, implementing such "complex" circuit breakers would be difficult. In this section, we focus on simple circuit breakers that depend only on the nature of the shock experienced by each country independently.

We thus assume that if

$$\epsilon_i \le k$$

the country is quarantined. Let υ be the probability of a quarantine. Then

$$\upsilon = G(k),$$

where $G(\varepsilon)$ is the cumulative distribution of ε. Then, with two countries, expected output per country with circuit breakers is

$$\bar{Q}(k) = (1-v)^2 E\left(F\left(\hat{S} + \frac{\epsilon_i + \epsilon_j}{2}\right) | \epsilon_i, \epsilon_j \ge k\right)$$
$$+2v(1-v)\left[E\left(F(\hat{S} + \epsilon_i | \epsilon_i \ge k)\right) + E\left(F(\hat{S} + \epsilon_i | \epsilon_i \le k)\right)\right]$$
$$+(v)^2 E\left(F(\hat{S} + \epsilon_i) | \epsilon_i \le k\right)$$

we can find the optimal degree of liberalization, i.e. the value of k for which $\bar{Q}(k)$is maximized. It is possible to show that under fairly weak conditions on the distributions G and F, the optimal value of k, i.e. the value of k which

$$0 < k^* < K < \infty$$

$$\underset{\{k\}}{\text{Maximizes}}\ \bar{Q}(k)$$

is finite, and less than the upper bound on ε_i. That is, *there are some restrictions on capital flows that increase welfare.*

Similar results hold for N > 2, though the notation is more complicated.

V. Optimal networks

In the absence of circuit breakers, we can easily analyze the design of optimal connectivity. Assume we have an infinite number of countries[15] but that we can organize them into risk sharing clubs, each of which has N members.[16] The larger N, the higher the probability of system failure, but the better risk sharing. This suggests that there may be an optimal size to the risk-sharing club. It is the solution to

$$\max_{\{N\}} EF\left(\hat{S} + \sum \epsilon_i / N\right) p^N + (1 - p^N)\underline{Q}$$

Define N* as the solution to the above maximization problem. If p < 1, then it is clear that N* < infinity.

If

$$EF\left(\hat{S} + \sum \epsilon_i / 2\right) p^2 + (1 - p^2)\underline{Q} \geq p\left[EF\left(\hat{S} + \epsilon_i\right) + (1 - p)\underline{Q}\right]$$

then some liberalization is desirable.

Each of the clubs can be linked with each other through weak links, e.g.. if $\bar{S}^k$ and $\bar{S}^{k'}$ represent the (average) value of S in club S^k ($S^{k'}$), then the two clubs smooth with each other provided $|\bar{S}^k - \bar{S}^{k'}| < \delta$. This imposes limits on capital flows, and ensures that a system failure in k (k') does not get transmitted to a system failure in k' (k).

If we could design perfect circuit breakers, i.e. circuit breakers that would prevent contagion of a disaster from one country to the other, but allow risk sharing otherwise, it should be clear then that we should have full integration, for countries then could enjoy the benefits of diversification without paying the costs of contagion.[17] Unfortunately, such perfect circuit breakers cannot really be designed (though in the context of the models that we have formulated here, they could be.) There are a host of idiosyncratic shocks facing each country. It may be difficult to isolate which risk sharing agreement "trips" the country into

[15] This is only an assumption of convenience, which allows us to treat N as a continuous variable and to avoid integer problems in dividing up the world into optimal clubs.

[16] There is a parallel analysis for examining connectivity among banks or firms. We comment further on these alternative interpretations in section VII.

[17] This has been shown, for instance, in a variant of the model presented at the end of the previous section, in Zhang (2010).

systemic failure, and, as Section VII illustrates, even more difficult in a dynamic context, where a particular episode of adverse risk sharing has its most adverse consequences not at the moment, but in subsequent periods, as it (with other adverse shocks) contributes to a downward spiral.

In this section, problems in one country lead to that in others as a result of contractual arrangements relating to risk sharing. This is, of course, only one of several mechanisms through which a problem in one country can be transmitted to another, i.e. through which contagion occurs. Later, we discuss alternative channels of contagion, and the implications for network design. Moreover, in this section, we have focused on a simple organizational design, where countries are all (ex ante) identical, and where the question is, what is the optimal size of risk-sharing clubs? Later in the paper, we briefly discuss more general questions in international economic architecture.

VI. Linear output subject to bankruptcy

So far, we have modeled the economy as facing a trade-off between value of risk diversification—assuming that there is no system failure—and the likelihood of system failure. Financial market integration increases diversification possibilities, but may also increase the risk of system failure, at least for small N. We now consider a polar case where there is no value of risk diversification—production is linear in S, provided S is greater than some critical number S*, at which point system failure occurs, and a loss of –C occurs. The main concern then is to minimize the losses from system failure.

(a) Two outcome case

Assume that $S_i = -\alpha_1$ with probability q, α_2 with probability 1 – q, such that

$$q\alpha_1 - (1-q)\alpha_2$$

i.e. expected output without bankruptcy is zero, but if

$$S \leq 0,$$

the country goes bankrupt, with output – C, where

$$C < \alpha_1.$$

Hence, prior to liberalization, expected output is

$$-qC + (1-q)\alpha_2 = q(\alpha_1 - C)$$

Assume N = 2, and there is full liberalization. Then, there are two cases:

$\alpha_2 > \alpha_1$,

i.e. $q > .5$; and

$\alpha_2 < \alpha_1$,

i.e. $q < .5$.

We focus on the latter case—small probabilities of "disaster." Then with liberalization,

$$q\left(\sum S_i/2 < 0\right) = 1 - (1-q)^2$$

i.e. *both* countries go bankrupt if only one country has a bad outcome, and expected output (per country) is

$$(1-q)^2\alpha_2 - C(1-(1-q)^2) < -qC + (1-q)\alpha_2$$

Liberalization is unambiguously welfare decreasing. A slightly "tighter" threshold for bankruptcy gives more ambiguous results. Assume bankruptcy occurs if

$\Sigma S_i/2 \leq K < 0$. Then if

$$\alpha_1 - \alpha_2 > 2K$$

liberalization is welfare decreasing. In the other case, expected output is

$$-q^2(C - \alpha_1) > q(\alpha_1 - C)$$

There thus exists a critical value of q such that *if disaster occurs rarely but seriously* liberalization is welfare reducing. The critical q* is defined by

$$q^* = (1 - \varsigma)(1 - 2\varsigma)$$

where

$$\varsigma \equiv 2K/\alpha_1$$

If $\varsigma \geq 1$, then liberalization is always desirable. If $\varsigma = 0$ (K = 0)—the case discussed earlier—it is never desirable.

More generally, if there are N countries, there is a critical q* for each N and K such that if q < q*(N,K) liberalization is not desirable. So long as the probability of an individual country facing failure is greater than q*, liberalization lowers expected output.

The probability of all countries going into bankruptcy in a club of size N can be calculated in a straightforward manner. Define n* = Integer $\{\alpha_1/ \alpha_2)$, i.e. the smallest integer less than α_1/ α_2. Assume that n countries have a bad outcome, N – n a good outcome. Then, so long as n ≥ n* all countries go into bankruptcy. The probability of this can be derived from the binomial distribution. The probability that n > n*, P*(n > n*) is given by

$$P^*(n > n^*) = \sum_{i=n^*+1}^{N} \binom{N}{i} q^i (1-q)^{N-i}$$

It is obvious, using the law of large numbers, that if K = 0, as N goes to infinity, liberalization is never desirable.

(b) Case of multiple outcomes

Assume that

S_i = {- α with probability q, + α with probability q, and 0 with probability 1 – 2q}.

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We assume output in a country just equals S, in the absence of bankruptcy. Assume that, in a system of (full) risk sharing among N countries, system failure occurs when $\Sigma S_i \leq 0$, or equivalently, the average value of S in the system is negative, i.e.

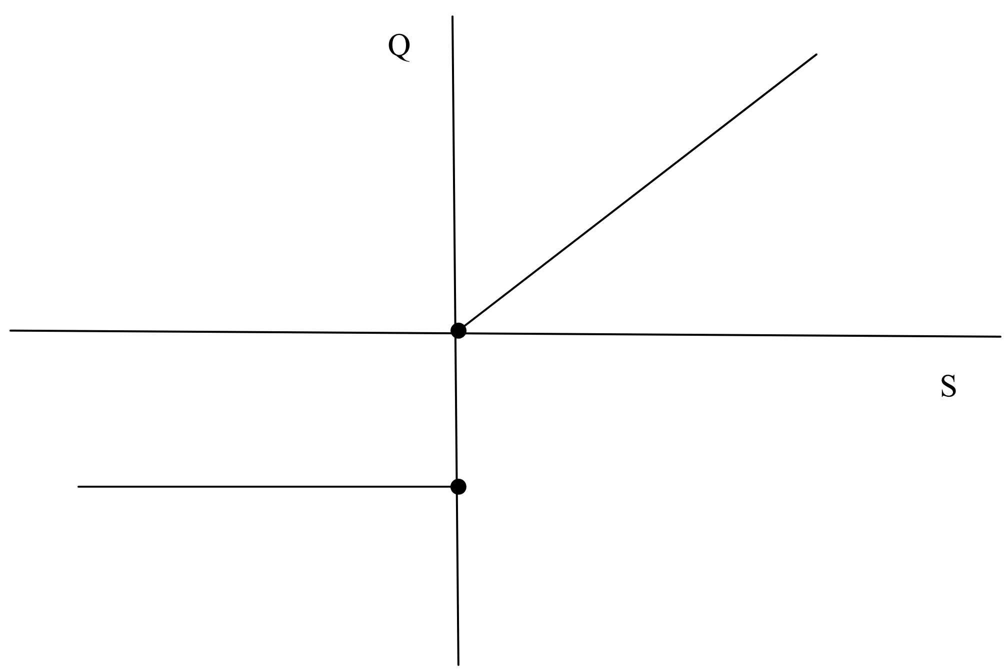
$$\Sigma S_i / N \leq 0.$$

If C = 0 (zero bankruptcy cost), then output

$$Q = \begin{cases} S \text{ for } S > 0 \\ -C \text{ for } S \leq 0 \end{cases}$$

is a convex function, so that risk sharing should be welfare reducing. If, however, C > 0, there is a strictly positive bankruptcy cost, then the "production" function is "S" shaped, being neither convex nor concave, so the welfare impacts of integration would appear to be ambiguous. (See Figure 1.)

Figure 1



Consider, for example, the case of N = 2. Then without integration, expected output per country is $q(\alpha - C)$,

There are six possible outcomes, given in Table 1. (For the moment, ignore the next to last column.)

Table 1

Country 1	Country 2	No integration	No integration, risk sharing	Integration
- α	- α	- C, -C	- C	- C
- α	0	- C, -C	- C	- C
- α	α	- C, α	(α – C)/ 2	-C
0	0	-C, - C	-C	-C
0	α	-C, α	(α - C)/2	α/2
α	α	α, α	α	α

No integration without risk sharing does better than integration in the case of {- α , α}, and worse in the case of {0, α}. The first occurs with a probability of $2p^2$, thee second with a probability of 2q(1-2q), so that integration is welfare enhancing if

$$2q^2 \{-2C - (\alpha - C)\} + 2q(1-2q)\{\alpha - [\alpha - C]\} > 0,$$

which implies that

$$q < C/ \alpha + 3C.$$

Integration is only desirable if q is sufficiently small. If C = 0, integration is never desirable, as expected.

If individuals are risk averse, so that the value associated with output Q is a concave function of Q, then integration is even less desirable than this calculation suggests, , since output is decreased (on average) in a state of nature that is worse (the state {-α, α} is worse than the state {0, α}.

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With N countries and full integration, system-wide failure will occur if $(1/N)\Sigma S_i \leq 0$. As N increases, by the law of large numbers, the average value of S converges to zero, and, at least half of the time, $\Sigma S \leq 0$, so expected output $\leq -.5C$. That is less than the output with no integration $q(\alpha - C)$ provided only that

$$q < .5$$

which will always be the case, provided that there is some probability of the zero outcome. *Full integration again never pays if there are enough countries*.

Note that this approach may overstate the gains from full economic integration. If countries are risk averse, they can still share risks *after production*, even if they are not fully integrated.

But a slight modification of the model shows how sensitive the results are to the specification of the bankruptcy conditions. Assume that bankruptcy occurs when $S < 0$ (rather than $S \leq 0$). Then the outcomes chart is changed to

Table 2

Country 1	Country 2	No integration	No integration, risk sharing	Integration
$-\alpha$	$-\alpha$	$-C, -C$	$-C$	$-C$
$-\alpha$	0	$-C, 0$	$-C/2$	$-C$
$-\alpha$	α	$-C, \alpha$	$(\alpha - C)/2$	0
0	0	0	0	0
0	α	$0, \alpha$	$\alpha/2$	$\alpha/2$
α	α	α	α	α

No integration does better when the outcomes are $\{-\alpha, 0\}$ (integration brings both into bankruptcy), while no integration does worse when outcomes are $\{\alpha, -\alpha\}$, for then integration avoids bankruptcy. Expected output with no integration is higher if

$$(1 - 2q)q\,[C/2] + q^2 (\alpha - C)/2 = \tfrac{1}{2} q \{C - q(3C - \alpha)\} > 0 .$$

Again, as expected, if $C = 0$, so the pay-off function is convex, this condition is always satisfied: *if there are no bankruptcy costs, integration is never desirable.* If there are bankruptcy costs ($C > 0$), then integration is not desirable if C is low enough

(i) $C < \alpha$,

Or,

(ii) if $C > \alpha$, if the probability of the extreme events ($+\alpha$, $-\alpha$) is low enough, i.e.

$$q \leq C/(3C - \alpha) \equiv q^*$$

A sufficient condition is that q is less than 1/3 .

With risk aversion, now integration is more desirable than these calculations suggest, because integration does worse than no-integration in the case of $\{-\alpha, 0\}$ and, if it does better, it is in the case of $\{\alpha, -\alpha\}$. With risk sharing, again, the benefits of integration are reduced, with everyone being better off *in every state of nature* with no-integration if $C < \alpha$; with expected utility being higher, if $q \leq q^*$.

More generally, no integration with risk sharing is thus preferable to integration if U(Q) is the (concave) utility function, if

$$(1\text{-}2q)[U(-C/2) - U(-C)) > q\,[U(0)) - U((\alpha - C)/2)]$$

With risk aversion, even if expected output is lower, expected utility can be higher (since integration performs better in a state of nature that is worse). The greater the degree of risk aversion, the higher the critical level of q.

The central insight of this section is that with bankruptcy costs, output is neither a convex nor concave function of S, so that whether integration is welfare increase or decreasing is ambiguous, and depends on the size of the bankruptcy costs, the probabilities of extreme events, and the degree of risk aversion. We have shown how in a simple example, one can identify precise values of the relevant parameters under which integration is and is not desirable. We have identified circumstances in which no integration is desirable, and provided more general condition under which full integration is *not* desirable. Risk mitigation does not, moreover, require integration: consumption risks can be shared, even in the absence of full capital market integration.

VII. A dynamic model

Even if risk sharing doesn't initially lead to a higher probability of bankruptcy, it can increase the probability of being *near* bankruptcy, and countries near bankruptcy may perform more poorly—engage in riskier behavior with lower expected returns—so that in the longer run output is lower. But even if they don't engage in riskier behavior, they are likely to have to pay higher interest rates, so that the likelihood that they face bankruptcy is enhanced.

This can be illustrated by a two period version of the model of the previous section. Assume that the critical value of S such that countries go into default is $S^* < 0$, so that, if N is large, with full integration, there is no bankruptcy the first period. To highlight the contrast between short run and long run results, we assume that bankruptcy costs are high, i.e. $C > \alpha$. Expected output with full integration in the first period is zero, greater than the output with no integration, which is $p(\alpha - C) < 0$. *In the short run, it appears that integration is beneficial.*

For simplicity, we assume that none of this output is consumed, but is passed on to the next period.[18] But now assume that in the second period, output is a random variable that depends on the value of S the firm inherits from first period, S_H, plus the amount of capital that it has available from the second period (itself affected by the extent of integration, i.e. in our formulation, risk sharing). We simplify by writing.

$$Q_2 = S_2 + \gamma(S_H)$$

where S_2, as before, is a random variable

$$S_2 = \{ -\alpha \text{ with probability } q, \alpha \text{ with probability } q, \text{ and } 0 \text{ otherwise}\}$$

and

$$\gamma = \{- \alpha - \ell \text{ with probability } q, \alpha - \ell \text{ with probability } q, \text{ and } 0 \text{ otherwise}\} \text{ if } S_H \leq S'$$

$$\gamma = \{ -\alpha \text{ with probability } q, \alpha \text{ with probability } q, \text{ and } 0 \text{ otherwise}\} \text{ if } S_H > S',$$

where $S' > S^*$, the bankruptcy level.

If the country inherits from the first period an amount below the critical threshold S', it will do more poor the second. For instance, a country (firm) with a low S may face higher interest costs. Others may be more reluctant to do business with a country (firm) that is more likely to be facing problems.

This stochastic process exhibits "trend reinforcement" (Battiston *et al.* 2009). (There are other reasons that economies may exhibit this property. In

[18] The results are unaffected if there is a simple (perhaps optimal) relationship between first period capital and consumption, which would determine the amount of capital available at the beginning of the second period.

Arrow's "Learning by Doing" model (1962), countries that produce or invest more learn more; so that successful countries have (in later periods) a more productive technology. This effect is reinforced if there is "learning by learning" (Stiglitz, 1987). Countries (like Ireland today) that have been hit by a large negative shock have a difficult time recruiting investors and business relations, because of the knowledge that taxes are likely to be higher and public services (including those valued by businesses) are likely to be lower. (The same phenomenon is exhibited at the firm level, and was evidenced in the East Asia crisis: firms that were believed to have a higher probability of bankruptcy had a harder time getting contracts, because buyers viewed such supplies as less reliable.)

We evaluate system performance by looking at expected final output (Q_2) minus bankruptcy costs associated with first period terminations. With no integration, expected losses the first period from bankruptcy are $-qC$ (assuming that $-\alpha < S^*$, i.e. those with bad outcomes go bankrupt). Expected output (the second period) from those who survive is $q(\alpha - C)$, so total expected output without integration, Q_{NI} is given by

$$Q_{NI} = -qC + (1-q)q(\alpha - C)$$

With full integration and a large number of countries (firms), all survive the first period. But now, expected output in the second period (with probability approaching 1 as N approaches infinity) is $-q\ell$. If $-\ell < S^*$, it implies that as N approaches infinity, the probability of systemic crisis approaches 1, so

$$Q_I = -C.$$

where Q_I is output with integration.

$$Q_I < Q_{NI}$$

if

$$-C < -qC + (1-q)q(\alpha - C)$$

Or

$$0 < (1-q)(C + q(\alpha - C)) = (1-q)((1-q)C + q\alpha)$$

i.e. always. *In this model, in the long run, it never pays to integrate, even though in the short run it appears that integration is desirable.*

On the other hand, if $-\ell > S^*$, then with full integration, expected output is $-\ell$. Now $Q_I < Q_{NI}$ if

$$-\ell < -qC + (1-q)q(\alpha - C) = q\,[(1-q)\alpha - (2-q)C],$$

i.e. if

$$\ell > q\,[\,(2-q)C - (1-q)\alpha],$$

The benefits of integration are that it avoids the bankruptcy cost, but if bankruptcy costs are low enough, then integration is never desirable. All that is required is that

$$C < [\ell/q + (1-q)\alpha]/2 - q$$

If $C \approx \alpha$, then the condition is satisfied if $C < \ell/q$.

VIII. Intuitive interpretation

There is a natural intuition behind our results. In the models presented here, output as a function of C is neither concave nor convex. Even if liberalization, by averaging, represents a mean preserving reduction in risk in the Rothschild-Stiglitz sense, it may increase the probability that S falls below a critical threshold, and it is this that trips the switch. Intuitively, economists who argued for liberalization made strong behavioral assumptions (that financial flows would be countercyclical, rather than pro-cyclical), which have been shown to be false. Theories of imperfect information and incomplete risk markets have helped explain why that may be the case. This paper has raised, however, another concern: that they also made strong structural assumptions, e.g. about concavity of all the relevant functions. With bankruptcy, externalities, financial market accelerator, R & D, learning, etc. we know that that is not the case.

In our simple model, risk sharing and gambling arrangements simply move capital around, in what might seem to be nothing more than zero-sum transactions. Conventional economics has emphasized that well designed risk sharing arrangements, however, constitute a "positive-sum" game; and with convex preferences and production sets that is the case.[19] By contrast, when there are non-convexities such as those associated with bankruptcy, risk sharing may convert a zero-sum game into a negative-sum game. Whether greater interconnectivity is net positive or negative thus depends on whether the first set

[19] Elsewhere (Stiglitz 1982) I have argued that much of the exchange of risks that occur in equity markets cannot be viewed as exchanges among rational individuals that are designed to increase their expected utility.

of effects, the diversification benefits, outweighs the second, the contagion costs. That depends both on the degree of risk aversion, the concavity of production functions (the extent to which they exhibit diminishing returns), the costs of bankruptcy, and the impact of sharing on the probability of bankruptcy.

This paper has developed concrete models in which we can weigh the diversification benefits against contagion costs, which we model, for simplicity, as arising from bankruptcy. Risk sharing transforms the probability distribution in complex ways that may increase or decrease the probability of bankruptcy, as we have seen. This depends in part on the bankruptcy threshold. Thus, in the model with two countries, with three outcomes, with symmetric gains and losses, in which risk sharing reduces the probability of a large loss ($-\alpha$). But it also increases the probability of *some* loss, and it can therefore increase the probability of both countries facing collapse. How risk sharing affects the probability of systemic collapse is thus a complex matter. Indeed, in another version of the model, with a large number of countries, full risk sharing can result in an almost zero probability of bankruptcy or a high probability of bankruptcy, depending on the relationship between the bankruptcy threshold and the limit value of the average.

This discussion should make clear some of the key qualitative determinants of the optimal degree of integration. The greater the concavity of the production function outside of bankruptcy, the greater the benefit of risk sharing; the greater the bankruptcy costs and the larger the risk of large negative shock, the greater the potential losses from "risk sharing." These intuitions have been confirmed by a large number of simulations, which suggest, even with simple probability distributions, complex patterns of interactions, with average output not even being a single peaked function of the size of the sharing "club."

(One aspect of the analysis is discomforting: the argument against risk sharing in "extreme" situations is that the stricken country is so badly off that the benefits to it (at the margin) of an extra dollar are, at least for the moment, less than that to others.[20])

In dynamic models, complex interactions associated with integration may make outcomes with integration worse. The model of the previous section highlights one effect, which Battiston *et al.* (2009) refer to as the Trend Reinforcement Effect: as countries get near default, there is an increased probability of moving toward default. Hence, even if countries have a lower probability in the short run of default, because of income smoothing, there may be a higher probability of poor outcomes, leading to a higher risk of default in the longer run.

[20] As the aphorism puts it: putting good money after bad.

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A further set of negative externalities associated with "trend reinforcement" arises from more complex interactions associated with bankruptcy cascades and price effects generated by default. The bankruptcy of one country heightens the subsequent probability of bankruptcy of those with which it interacts (Greenwald and Stiglitz 2003; Allen and Gale 2001; Battiston *et al.* 2007). Because trading partners know this, they may insist on higher interest rates, further increasing the risk of default in subsequent periods.

There are other instances in which it has become commonly accepted that risk diversification is not optimal: after a banking crisis, it is common to argue for stripping out the bad assets, and forming a good bank and a bad bank. There are two arguments for such "unmixing," both based on non-convexities. One is the benefits of specialization in management, with one bank focusing on disposing of the bad assets, and the other in making new loans and managing good assets. The other heuristically sees lending as a diminishing function of risk (say as measured by the coefficient of variation), with lending reaching zero, say, at a particular critical level of risk. If that level of risk has been attained, stripping out the good (low variance) assets creates an institution that is willing and able to lend. There is no loss in lending from the other part—since lending in any case was zero. (The argument is particularly compelling when there are macro-economic externalities associated with lending.)[21]

There are many other bases of contagion, consistent both with the metaphor of contagion and the mathematics of non-convexities, with accompanying results that also suggest that the benefits of integration need to be balanced with costs. The origin of the word is associated with the spread of a disease, and the standard mathematic model shows the value of quarantining. If there are two isolated populations (say of equal size) with a proportion p_i of the i^{th} population diseased, then the increase in numbers with the disease is proportional to

$$\sum p_i (1 - p_i),$$

but if the two populations are mixed together, the increase is proportional to

$$2p^* (1 - p^*)$$

where $p^* = ½ (p_1 + p_2)$.

It is easy to show that

[21] For a more complete analysis of the relationship between bank portfolios and their lending decisions, see Greenwald and Stiglitz (2003).

$$\sum p_i (1 - p_i) < \quad 2p^* (1 - p^*)$$

so long as p_1 does not equal p_2, i.e. quarantines slow the pace of the diffusion of the disease.

Standard analysis (pre-crisis) focused on "conservative" systems, where a fixed shock was subject to division through diversification/risk sharing, thereby diminishing the adverse impact. But with contagion, there can be amplification; one diseased person can transmit the disease to many others. The system is not, in this sense, conservative. In one way or another, models of contagion entail some form of amplification, where the total impact can be increased with an increase in connectivity.

There are many channels through which connectivity and amplification are linked. For instance, market participants are risk averse. Assume that country A has a serious problem, and country A is linked (directly and indirectly) with a series of other countries. Market participants then know that there is a risk of a problem in any country with which there is connectivity—and if there is a risk of amplification, then the greater the extent of connectivity, the greater the systemic risk (the essential point of this paper.)

Assume, for instance, that country A has a loss of L, and that is has contracts that share that loss with n other countries $\Sigma L_i = L$, . Assume, for simplicity, the cost to each is linear in L_i, the loss it absorbs, provided $L_i < L^*$, but is C for $L_i > L^*$, where we assume C is large, and > L. If the risk is shared evenly, then for large L, the total loss is $nC > L$ for $L/n > L^*$, i.e. for $n < L/L^* \equiv n^*$, and L^* for $n > L/L^*$. Thus, as figure 2 illustrates, societal loss increases as n increases, until it reaches the critical threshold, L/L^*, in which case the benefits of diversification dominate:

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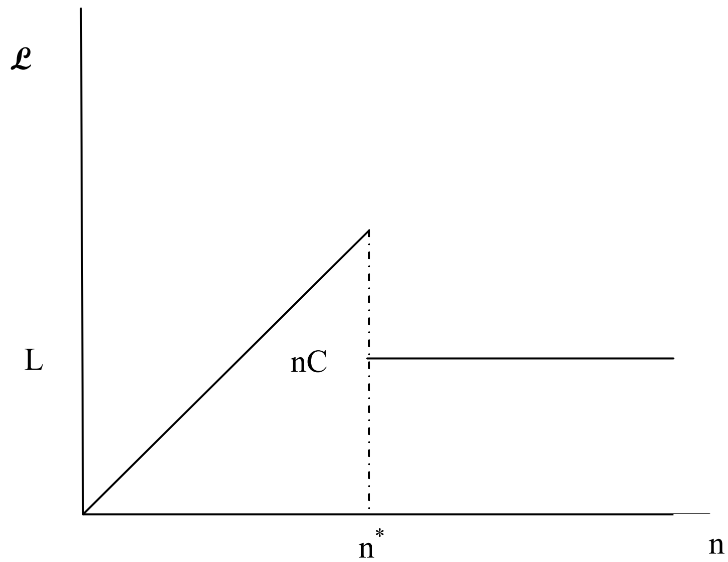
Figure 2

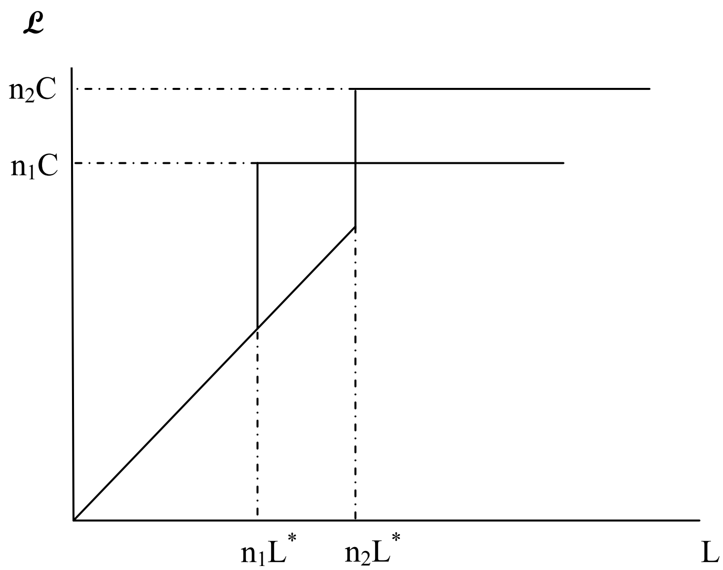
$$\mathcal{L} = \begin{matrix} -nC \text{ for } n < n^* \\ L^* \text{ for } n > n^* \end{matrix}$$



With L and L* known, the optimal degree of diversification is clear: we set n > n* if n* < N, the total number of countries, and equal to 0 otherwise. We either diversify the risk so much that it presents no problem for any country, or we "quarantine" the risk in the country of origin. Assume now that L is a random variable. Figure 3 shows the trade-offs. It plots total loss as a function of L, for fixed n (degree of diversification) so long as L is small enough, diversification pays. But if L is large, there are large losses from the contagion. If n is increased (a higher degree of diversification), diversification can handle a larger L. But when L is large, total societal costs are increased. There is an optimal degree of diversification.[22]

[22] The analysis is parallel if there is uncertainty about the capacity of each country to absorb risk before confronting bankruptcy, i.e. over the value of L*

Figure 3



But now assume that there is risk about how the loss is divided. Assume, for instance, it is known that the risk is divided among n countries, $n < n^*$, but there is a lack of transparency, so it is not known which countries. Hence, each country now faces a risk of a loss of –C with probability n/N, where N is the total number of countries. The market value of each will be decreased by nC/N, and each will find it more difficult to raise capital. As Section VI illustrated, this in turn will have its own amplification effect; uncertainty can amplify the amplifications.

IX. Some broader perspectives on contagion and circuit breakers: Macroeconomics

The analysis of this paper constitutes only part of a broader investigation into the economics of contagion, which asks how problems in one country can spread, having adverse effects on others. Much of the policy debate has focused on responses to crises—how to prevent "contagion" once a crisis has occurred. A central message of this paper is that if there is a possibility of contagion, one needs to incorporate that into the analysis of policies and structures *before* a crisis occurs. While there has been some recognition of the need to take actions (e.g.

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policies) that reduce the likelihood of the occurrence of a crisis,[23] we have emphasized the need to design policies and structures that are sensitive to contagion itself. Capital and financial market liberalization, for instance, exhibit the two-sided nature of risk sharing upon which we have focused: they may enable risk smoothing, but they may also result in problems in one country leading to problems in others.

But the word contagion is used in the context of a sick country only as a metaphor, and the question is, what are the specific channels through which a sick country might infect others? This paper has explored one important set of channels, through risk sharing contracts. While to give our model concreteness, we have presented the model as if it involved *physical* capital, a better interpretation entails *financial capital,* payments from healthy countries (firms, banks) to sick countries (firms, banks), leading to problems in the healthy countries.[24]

There are three other widely discussed channels. The first is trade. A weak economy buys less from the strong economy, and thus weakens it. (This channel was important during the recent crisis in the transmission of the financial crisis in the developed countries to the developing countries.) But quarantining exacerbates the problem. Indeed, ex ante, there is an argument for export diversification, and because of macro-economic externalities, societal benefits from such diversification exceed private benefits, so governments might wish to encourage it.

A second is through expectations. At least since Keynes, the role of expectations and "animal spirits" has been emphasized. An economic downturn in one country might rationally bring fears about the prospects of others who are linked to it through trade or finance, or at least raise new uncertainties, but even if the responses may be greater than can be accounted for by rational expectations, the economic consequences are no less real.

(Though I couch the linkages in terms of adverse shocks, analogous impacts arise in the presence of positive shocks: a wave of optimism can spread, inducing both lenders and borrowers to undertake high levels of lending and borrowing, with untoward consequences when the animal spirits become tamer.[25])

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[23] See, for instance, Orszag and Stiglitz (2002).

[24] While the unit of analysis of the models presented in this paper is countries, most risk sharing contracts are between firms (including banks) within countries. In effect, this paper looks at the macroeconomic consequences of those risk sharing arrangements, no matter how they arise. In the next section, we discuss the consequences of connectivity among firms (banks), ignoring the underlying macroeconomic structures. The analysis is best viewed in the context of relationships among institutions *within* a country. Future research will attempt to link more formally these two strands of work.

[25] There is a large literature on contagion through one or more of these (or other) channels, both within the literature in financial economics and international economics. See, for

The expectations argument seems to have played a major role in motivating some of the IMF bailouts in earlier decades, but much of the analysis was suspect (Stiglitz 1998). Indeed, if Mexico's economy stabilized *because* of an IMF bailout, and if it appears that Argentine would not be bailed out, then the Mexican bailout arguably should have exacerbated Argentina's conditions, as investors realized the hopelessness of its situation. Moreover, the interventions were typically described as temporary. If markets were rational, why would they believe that a temporary intervention, say, in Thailand, to bolster its exchange rate today would have long run effects? If the demand curves for its currency (its products, investments in the country) have shifted down in a way to lead to a large change in exchange rate, why would a temporary upward shift in the demand curve, supported by bailout funds, have long run permanent effects in that country, let alone change longer term expectations about economic conditions in other countries, or the equilibrium exchange rate?[26]

Part of the answer for why such interventions could have real effects is not *just* expectations; there can be real consequences to an even temporary large change in the exchange rate. If firms have borrowed in foreign exchange, their balance sheet will have changed adversely. They may have difficulty servicing their debt. Domestic banks that have lent to them in local currency may demand more collateral or a higher interest rate. Bank regulators, worrying about the risks confronting banks, may be more stringent in their supervision.

Worse still, other market participants will be uncertain about the balance sheets of firms, households, and banks. And they will respond to this uncertainty with changing terms of contracts in adverse ways (e.g. charging higher interest rates on trade credit or demanding more collateral on loans). It is this uncertainty that acts much like a contagious disease; is not subject to "zero sum" properties. Uncertainty about the future exchange rate between country A and B will adversely affect both A and B. And it is here that structure matters: if A and B are closely integrated, a shock to A will result in uncertainty about B's economy.

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instance, Banerjee (1992); Bernanke, Gertler and Gilchrist, (1999), Bikhchandani, Hirshleifer and Welch (1992); Brunnermeier (2009); Brunnermeier and Pedersen (2009); Enders, Kolman and Müller (2010); Gertler and Kiyotaki (2010); Kaminsky, Reinhart and Vegh (2003); Kiyotaki and Moore (2002); Suarez (1994); and the references cited in those papers. Kodres and Pritsker (2002) present a rational expectations model of financial contagion in which portfolio rebalancing transmits idiosyncratic shocks across markets. Calvo and Mendoza (2000) present a model in which globalization may increase financial contagion by decreasing investors' incentives to gather market-specific information. See the discussion in the next section.

[26] The one set of arguments relates to liquidity and the existence of multiple equilibria. There is a large literature explaining why there may be multiple equilibrium, with sudden changes from one to another. (Greenwald and Stiglitz 2003 provide illustrations in models with bankruptcy. Hoff and Stiglitz (2001) and Shin (2000) provide more general discussions in the context of development and macroeconomics. In Diamond and Dybvig's (1983) model of bank runs, government guarantees can prevent the "bad equilibrium" from occurring.

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Some of the "advances" in financial markets have exacerbated these problems. Companies can take out multi-billion dollar foreign exchange swaps, so large that their settlement can have macroeconomic effects. But there is no transparency to these over-the-counter products, no transparency to the counterparties, no ability, accordingly, for the market to assess the risks. Correlated behavior associated with herding further opens up the possibility of high volatility in certain asset prices, exacerbating the risk of sudden changes in balance sheets, with macroeconomic consequences.[27]

Restrictions on integration may reduce these risks, and thereby increase systemic stability. We have emphasized in this paper that one must balance out the benefits of integration with these costs. Moreover, the consequences of "contagion" are linked with the magnitude of amplification effects, and these in turn can be affected by policy, e.g. banking regulation, to which we turn in the next section.

X. Some broader perspectives on contagion and circuit breakers: Financial markets and general equilibrium theory

The central insight of modern welfare economics is that when information is imperfect and asymmetric and risk markets incomplete, markets are not in general constrained Pareto efficient. Decisions made by individuals and firms e.g. with respect to risk sharing and risk taking may be privately profitable but lead to adverse systemic performance, increasing systemic risk. This is true even with rational expectations.[28]

(The discrepancy between social and private returns not only explains the inefficiency of markets, but also why certain 'financial innovations" may have led to more systemic instability and poorer overall performance.)

Each individual, for instance, may take the price distribution of housing (or the extent of liquidity in the market) as given, but their collective decisions

[27] Herding behavior can even occur in the context of rational expectations. Incentive structures based implicitly or explicitly on relative performance can also induce correlated behavior. See Nalebuff and Stiglitz (1983). See also Banerjee (1992)

[28] Newbery and Stiglitz (1982) showed how rational responses to exogenously determined risk (e.g. associated with variable agriculture output related to weather) lead to inefficient outcomes, even with rational expectations. This result was generalized by Greenwald and Stiglitz (1986) who showed that the actions of market participants gave rise to pecuniary externalities, which, in the presence of imperfect risk markets and incomplete information, mattered, i.e. markets were never constrained Pareto efficient. In traditional welfare economics, small price changes did not matter—they were essentially redistributive, with the benefits of those who gained from say higher prices offset by the buyers who lost. But when there are incentive compatibility and self-selection constraints, price changes affect how those constraints bind, and have a first order effect. See Arnott, Greenwald, and Stiglitz (1994).

affect those prices (or the extent of liquidity). Together, their actions may lead to a bubble and a housing crash; each rationally believes that these events are not caused by its own actions. But this volatility is *man-made*; it is not *just* the result of exogenous shocks, like those induced by the weather.

For the past fifteen years, the analysis of financial systems (and macroeconomic systems more generally) has proceeded along two different courses.[29] One has assumed that there are exogenous shocks, and described how the system responds to those shocks. This view has predominated in policy making circles, and led to the Basle II standards, in which each bank assessed its ability to withstand the kinds of volatility that had been experienced in the past.[30] Even from the onset, critics warned not just of the technical flaws and the reliance on credit rating agencies, whose credibility (and incentives) had been questioned in the context of earlier crises (Ferri, Liu and Stiglitz 1999), but of the underlying assumption of exogenous risks (Danielsson *et al.* 2001).

The other view stressed not only that risk itself was endogenous, but also that markets are not in general (Pareto) efficient, either in their decisions about risk taking, including their arrangements about risk sharing, the information that they gather to help manage risk, and the transparency with which they function.[31]

Most of the analysis of this paper describes how economic arrangements affect how the economic *system* responds to exogenous risks, e.g. by amplifying the consequences, so that the risk faced by any unit (e.g. a bank or a country) is largely endogenous to the system. But risk can be totally endogenous, i.e. there is no intrinsic source of shocks, but rather, the system creates the noise with which it then must cope. This is true of many of macroeconomic shocks, from the tulip bulb mania to the housing bubble of recent years.[32]

Thus, a full analysis of system risk and contagion must address (i) equilibrium contractual arrangements, and how they transmit risk from one unit to another; (ii) incentives for disclosure (or secrecy) and gathering information, which affects how the system exposes itself to and responds to risk; (iii) the

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[29] I am indebted to an anonymous referee for suggesting that I emphasize these distinctions.

[30] Many of those who held these views did not change their perspectives after the crisis. They believed that the financial markets had just been swept by a once-in-a-hundred year flood that was not of their own making.

[31] There are complex interactions among these, some of which we note below. As systems of managing risk improve, market participants may undertake more risky activities (as noted by Greenwald, Stiglitz, and Weiss, 1984). Individuals may gather less information. The net effect of these changes is that systemic risk performance may improve much less. Indeed, as the current crisis suggests, it may even worsen.

[32] Sunspot equilibria are also of this sort. For an example in the context of financial markets, where markets can oscillate between high interest regimes, with high default probabilities, to low interest regimes, with low default rates, see Greenwald and Stiglitz (2003). In some contexts, the only market equilibria entail market-created noise. See, for instance, Stiglitz (forthcoming).

sources of amplification, because, as we have suggested, without amplification, risk sharing would disperse risk and reduce its consequences. A complete analysis is beyond the scope of this short paper, but in the following paragraphs, we call attention to several key aspects.

Amplification

Amplifications are important not only because of the role they play in contagion, but also because they can imply large consequences from small shocks.

Earlier, we discussed the channels through which a problem in one country can be transmitted to another. There is a parallel set of channels within the financial sector, with some more prone to amplification than others. Among the channels are: (a) risk sharing contracts, so that a loss by one financial unit is shifted (shared) with others; (b) contagion through price effects, as firms faced by an adverse shock attempt to sell their assets; asset price changes affect both balance sheets and credit constraints; (c) indirect effects through the real sector, e.g. as problems in the financial sector dampen real economic activity, with adverse effects even on banks that had done a good job in credit assessment; (d) indirect effects as a result of financial market imperfections, as financial institutions that are, in one way or another, affected by a shock are forced to adjust their lending and investments; and (e) impacts through expectations, as the crisis in one country forces Bayesian investors (and even more so, those forming expectations in less rational ways) to adjust beliefs. Recent crises illustrate each of these channels. The breaking of the housing bubble in the United States led those in other countries with bubbles to reassess the likelihood that they too had a bubble—especially as it totally undermined the belief that markets were rational and that therefore there could be no bubbles. In 1998, the Russian crisis provided no insights into what was occurring in Brazil; but there were a few key firms investing in both Brazil and Russia, and losses in Russia forced quick sales of Brazilian assets. In this crisis, while the financial sector played a central role in the economic downturn in developed countries, many developing countries, with well regulated financial sectors, nonetheless subsequently faced problems in the financial sector as the collapse of trade weakened the real sector.[33]

Ironically, such risk sharing contracts were supposed to enhance the ability of the economy to withstand risk. It is clear that in the recent crisis, such contracts (not just the ill-fated asset backed securities, but also derivatives, including credit default swaps) played a central role in the creation of the crisis. One of the central objectives of this paper has been to explain why that might have been the case, by questioning the underlying mathematical structures that

[33] Greenwald and Stiglitz (2003) provide evidence of the role that this channel played in the context of regional shocks, e.g. associated with the decline in oil prices in the 1980s.

had been assumed by those arguing that such contractual arrangements necessarily enhanced economic stability. But beyond that, it is important to understand the specific economic mechanisms through which amplification occurs.[34]

Credit constraints (themselves related to imperfect information) can easily give rise to amplification. The financial accelerator (Greenwald and Stiglitz, 1993) implies that a change in a firm's net worth can give rise to a multiple increase in its demand for investment or its ability to produce.[35]

More generally, small change in prices can have first order effects on welfare (and behavior). This is a corollary of the Greenwald and Stiglitz (1986) theorem. Economies with incomplete risk markets and imperfect information in this respect, from the standard model, for which it can be shown that small price perturbations have second order effects on welfare (a result that is a straightforward application of the envelope theorem). Thus, it is not the case that a shock that increases, say, foreign exchange rates is purely redistributive, with the benefits of those who lose offset by those who gain.

Market failure

The failure of the price system to work in the way that it is supposed to is particularly evident when there is a risk of bankruptcy. Modern capitalism requires limited liability (Greenwald and Stiglitz, 1992), but at the same time, with bankruptcy, private and social incentives are never perfectly aligned. Increased risk taking may, for instance, reduce the value of outstanding bonds, and bond covenants designed to prevent such actions are inevitably incomplete. Changes in bankruptcy probabilities also have effects on the firms' suppliers and customers, externalities to which firms are unlikely to pay adequate attention.[36]

The failure of markets arises not just because one could not rely on banks to manage their own risks in their own interests, but that because of pervasive externalities, even if it they did so, the decisions they made were not necessarily in the best interests of society. This would be so even without the (implicit or explicit) government safety net, but the misalignment between private and social

[34] Key insights are provided by Korinek (2010).

[35] Kiyotaki and Moore (1997) show that the dynamic interaction between credit limits and asset prices turns out to be a powerful transmission mechanism by which the effects of small shocks persist, amplify, and spill over to other sectors. See also Miller and Stiglitz (forthcoming.) Bank runs represent an example of a sudden change in the state of the economy (Diamond and Dybvig 1983). A run on one bank can, under some economic structures, give rise to bankruptcy cascades. (Allen and Gale 2001, Greenwald and Stiglitz 2003).

[36] In traditional economic theory (including finance theory) bankruptcy played no role. In my 1969 paper on the Modigliani-Miller theorem, I first argued that bankruptcy played a critical role in the analysis of equilibrium, an idea on which I subsequently elaborated in Stiglitz (1972).

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incentives is obviously particularly severe with too-big-to fail institutions and in the presence of deposit insurance.

The problems with the market are deep, and as I have said, would arise even in the absence of government intervention. Markets are rife with agency problems and (with imperfect information and risk markets) externalities, so private and social returns are often misaligned. As a result of by now well known problems in corporate governance, firms in the financial sector provide incentives for their decision makers to undertake excessive risk and to be short sighted—with results that were predictable, and not in general consistent with the interests of shareholders and bondholders, let alone the rest of society (Stiglitz, 1985).

Agency problems are, of course, pervasive in a modern market economy. But market participants sometimes respond in ways which increase their magnitude, e.g. to give managers more control, so they act more in their own interests, less in that of other stakeholders, including shareholders (Edlin and Stiglitz 1995). They can do so, for instance, by acting in ways which increase information asymmetries. They have incentives for non-transparency—so evident in the recent crisis.

Securitization, for all its virtues in risk diversification, created whole new sets of agency problems and conflicts of interests,[37] some of which had been anticipated even as the securitization movement was in its infancy (see Stiglitz 1992).

But securitization, and risk diversification more generally, attenuated incentives to gather information. This is an inherent problem, which the advocates of securitization ignored. They believed in efficient markets, failing to recognize the internal inconsistency in the efficient markets hypothesis: If markets perfectly conveyed information (as the advocates of informationally efficient markets claimed), then there would be no incentives to gather information (Grossman and Stiglitz 1976; 1980). Systems that disperse risk inherently weaken "accountability" and incentives not just for gathering information, but for ensuring the "quality" of the financial products being produced. If diversification leads to an attenuation of incentives for obtaining good information,[38] it can lead not only to poorer overall performance, but more instability. Hence, the trade-off is markedly different than has traditionally been envisaged in the securitization literature, where it was presumed that securitization would lead to enhanced systemic stability.

[37] See, for instance, Stiglitz, 2010b. What was remarkable was that market participants (in particular investors) seemed almost oblivious to these problems. Credit rating agencies used past data to estimate default probabilities, even though the quality of mortgages being written had greatly deteriorated—reflecting the changed incentives that had resulted from securitization.

[38] As in Calvo and Mendoza (2000).

By the same token, because markets that are fully transparent are more competitive, and less profitable, there are strong market incentives for reducing and impeding transparency.

Networks and Linkages

This paper has focused on the consequences of risk sharing arrangements among countries, but the analysis is equally applicable to risk sharing arrangements among firms. Most of the literature on architecture has, in fact, focused on financial markets, not linkages among countries (Gallegati *et al.* (2008) is an exception).[39] The central results are (a) economic architecture matters; and (b) private incentives are not necessarily aligned with those of society.

Our analysis has focused on linear risk sharing contracts, but actual markets employ far more complex (and far riskier) non-linear contracts, whose motivation is not just risk sharing. They arise out of differences in judgments about probabilities.

One of the key issues upon which we have focused—how risk-sharing arrangements can lead a "crisis" in one country to generate a crisis in other countries with which it is connected has its parallel in the financial literature: how a bankruptcy of one firm can generate a bankruptcy cascade (Allen and Gale, 2001; Greenwald and Stiglitz, 2003). The structure of the credit market (its architecture) affects the probability of such a cascade.

In the context of cross-country capital flows, we have shown how capital controls can ameliorate the risks of contagion. Some have suggested that "resolution authority" provides a parallel mechanism in financial markets.[40] I am not sure that is the case, for several reasons: First, at best, resolution authority can be thought of as a form of "pre-emptive bankruptcy," protecting depositors (and thereby the government, as a result of its implicit or explicit obligation to depositors); but it is designed to ensure that others (including bondholders) bear losses, thereby still exposing the system to the risk of a bankruptcy cascade, though perhaps one that might not be as serious as would have occurred had such pre-emptive actions not been undertaken. Secondly, there is a concern that governments will be reluctant to exercise resolution authority in time of crisis,

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[39] While, as we have noted, most of the finance literature ignored these issues, there is by now a growing literature exploring the consequences of what I call financial architecture. These include Allen and Gale (2001); Allen and Babus (2009); Allen, Babus, and Carletti (2010); Arinaminpathy, Kapadia and May (2010), Battiston *et al.,* (2007, 2009); Boissay (2006); Boss, Summer and Thurner (2004); Castiglionesi and Navarro (2008); Delli Gatti *et al.* (2006, 2009); De Masi *et al* (forthcoming); Eisenberg and Noe (2001); Friexas, Parigi and Rochet (2000); Gai and Kapadia (2010a, 2010b); Haldane (2009); Haldane and May (2010); Nier *et al.* (2007); and Shin (2008).

[40] For a discussion of these issues, see, e.g. Bank of England (2009a)).

just as the American government was reluctant to the powers at its disposal in the recent crisis.[41] By contrast, there are natural incentives on the part of governments facing capital outflows in times of crisis to impose capital controls.[42]

In short, in the analysis of systemic risk associated with alternative architectures, it should not be assumed that resolution authority will either be invoked or be fully effective. To avoid systemic risk, there will need to be restrictions in the set of admissible risk contracts—recognizing that contractual arrangements that may be privately profitable may be socially undesirable.

Regulatory problems

More generally, policies and rules endogenously determine the extent and form of risk taking and the nature of risk-sharing arrangements. Different policy frameworks (rules of the game) can lead to different financial architectures; some architectures may be more stable, with less risk of systemic failure, some may provide better incentives for gathering and processing information, some may be more efficient.

A major objective of the research agenda, of which this paper is a part, is to ascertain what rules of the game (regulations) might lead to better outcomes.

For instance, the regulatory system itself contributed to these cyclical fluctuations; they acted in a pro-cyclical manner. For years before the 2008 crisis, academic economists had called for macro-prudential regulations to offset these effects. (See Griffith-Jones, Ocampo and Stiglitz (2010), and the references cited there; Bank of England (2009b), and Turner (2009). For a broader discussion of the problems with the Basel II regulatory regime, see Danielsson *et al.* (2001).)

Earlier, we stressed the importance of bankruptcy. The laws governing bankruptcy affect the risks which market participants are willing to bear. It is even possible that well-designed bankruptcy laws can contributed to systemic stability.[43] In the other direction, some have argued that America's bankruptcy reform of 2005 may have contributed to the housing bubble (Stiglitz 2010b).

Cognitive equilibrium and herding

Financial and capital market liberalization contributed to the contagion of the crisis that was borne in part from financial sector deregulation and the belief that

[41] In particular, politically influential bondholders will argue—as they did in the recent crisis—that forcing them to take a "haircut" will have systemically calamitous effects.
[42] In the past, pressures from the financial markets were exerted not to impose such controls; but increasingly, governments, and even the IMF, have come to recognize the desirability of imposing such controls, at least under certain circumstances.
[43] See, for instance, Miller and Stiglitz (forthcoming, 1999).

all that Central Banks needed to do to ensure stability and growth was to maintain inflation at low levels. These ideas had become the fashion of the day, as were other widely held tenants, such as that because risk was spread so widely, the economic system was far more stable, able to manage virtually any risk that it might face.

Hoff and Stiglitz (2010) describe how individuals beliefs affect both behavior and how they gather and process information; they process information in a way which reinforces preconceptions, so that there can be *equilibrium fictions*. Thus advocates of the efficient markets hypothesis and related doctrines, both within the private and public sector, dismissed evidence to the contrary. Anand, Kirman and Marsili (2010) construct a model in which there is an equilibrium in which no one scrutinizes the mortgages embedded in MBS's, in part because they know that when they come to sell the securities, no one will monitor the constituent mortgages.

But belief systems can change rapidly; the equilibrium supported by this particular belief system can quickly disappear.[44] This crisis, for instance, showed (or should have shown) that prevailing beliefs might not be correct, and in doing so dramatically increased uncertainties (in effect, reducing the "false" certainties to which previous systems had given rise).

Such changes in belief systems can give rise to contagion: ideas flow easily from one place to another. Economic connectivity of the kind upon which we have focused may accelerate such contagion, but it is neither necessary nor sufficient.

XI. Concluding comments

We have constructed a simple model in which, in the absence of system failure, full liberalization would be desirable. But with full liberalization, a "failure" in one part of the system (in one country) can result (through contagion) in system failures in other countries. We show that if we can only have full liberalization or no liberalization amongst a set of countries, then no liberalization may be preferable.

But these are not the only choices available. We have argued that attention needs to be focused on the design of *economic architecture,* on the nature of, say, risk sharing relationships among countries. However, if we can impose restrictions on capital flows (create circuit breakers), then it will, in general, be desirable to do so. Without circuit breakers, no liberalization may be

[44] See, for instance, Bikhchandani *et al* 1992

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preferable to liberalization; but with circuit breakers, a higher degree of integration may be desirable. In the context of one simple model, we showed that there is an optimal size of the "club" amongst whose members there is full liberalization. If the different clubs can be linked together, with limited capital flows between them, it may be desirable to do so.

There is a broader question, which we not have been able to address in this paper, and that is the optimal *architecture,* especially in the case of countries of different sizes. There is an obvious question: Is it better to have clubs of similar sized countries? But there is a more general set of questions: If, for instance, various countries can be linked together with different degrees of integration (different parameters at which the circuit breakers are tripped), is it optimal to have all countries symmetrically interlinked, or is it desirable to have clusters of countries that are closely interlinked, with the clusters then loosely interlinked? If there are a few large countries, is it optimal to have these large countries act as nodes in a network, with the nodes linked to each other? We suspect that, under a variety of conditions, optimal network design in fact entails asymmetries in linkages, with large countries that are better able to withstand shocks serving as nodes in the network. [45]

We have noted that while we have couched most of the analysis of this paper in terms of linkages among countries, much of what we have said is equally applicable to linkages among financial institutions.

Pictures of observed patterns of linkages in credit markets (Haldane [2009], De Masi *et al.* [forthcoming]) often exhibit architectures with a few nodes, with different banks linked closely to one or another node, and these "big banks" linked with each other. Such a system may be able to absorb small shocks (problems in one or more banks linked to a particular node are diffused well throughout the system), but large correlated risks can give rise to systemic risk. Our analysis has provided insights into why that may be the case.

The question of optimal risk architecture, assessing the risk properties associated with these different architectures, is one that we hope to investigate in a subsequent paper.

[45] Models of banking have analyzed how bank interdependence can give rise to bankruptcy cascades. The likelihood of such cascades is related to the structure of interconnectedness. See Greenwald and Stiglitz (2003), Allen and Gale (2001), Haldane and May (2010).

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