Contagion in Latin America:
Definitions, Measurement, and Policy Implications*

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Abstract: This paper analyzes bond and stock markets in Latin America and uses these patterns to investigate whether contagion occurred in the 1990's. It defines "shift-contagion" as a significant increase in cross-market linkages after a shock to one country or region. Several coin-toss examples and a simple model show that the standard tests for contagion are biased due to the presence of heteroscedasticity, endogeneity, and omitted-variable bias. Recent empirical work that addresses these problems finds little evidence of shift-contagion during a range of crisis periods. Instead, this work argues that many countries are highly "interdependent" in all states of the world and the strong cross-country linkages that exist after a crisis are not significantly different than those during more stable periods. These findings have a number of implications for Latin America.

1. Introduction

The last two decades have shown that if any country in the world sneezes, Latin America catches pneumonia. A summary of Latin America's recent medical history would include: the Mexican Debt Crisis in 1982, the Tequila Effect in 1994, The Asian Flu in 1997, the Russian Cold in 1998, the Brazilian Fever in 1999, and the Nasdaq Rash in 2000. No wonder insurance for the region is costly!

These increasingly frequent crises have attracted the attention of policy makers and academics. Of particular interest is why many of these crises that began as country-specific events quickly affected countries and regions around the globe (such as Latin America). Most people describe these patterns as "contagion". One peculiarity about this literature is that although there is fairly widespread agreement about which of these events led to contagion in Latin America, there is no consensus on exactly what constitutes contagion or how it should be defined. One preferred definition of contagion is: the propagation of shocks in excess to that which can be explained by *fundamentals*.[1]

A simple example shows the practical difficulties in using this definition for a discussion of contagion. In the month after the 1998 devaluation of the Russian ruble, the Brazilian stock market fell by over 50 percent. Is this contagion? Can this impact of Russia on Brazil be explained by any fundamental linkages? A preliminary analysis would suggest no. Russia and Brazil have virtually no direct trade links; the two countries do not export similar goods that compete on third markets; and they have few direct financial links (such as through banks). Further analysis, however, might indicate that during the Russian crisis the market *learned* how the IMF would respond during the next currency crisis and what sort of rescue package it would implement. This learning process may have conveyed valuable information about potential rescue packages for the next countries that devalued their currencies and/or defaulted on their international debt.

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[1] For example, a shock to Mexico could affect stock prices in Argentina if the shock causes a depreciation of the Mexican peso which increases the competitiveness of Mexican exports relative to Argentine exports. This could, in turn reduce the earnings and dividends of Argentine firms which compete with Mexican firms in third markets. Since the transmission of the initial shock from Mexico to Argentina can be explained by fundamentals (competitiveness effects in third markets), this would not constitute contagion.

An examination of stock market performance and public debt prices for countries in Latin America supports this interpretation. For example, Figure 1 graphs aggregate stock market indices for Argentina, Brazil, Chile, Colombia, Mexico and Venezuela during the Russian crisis.[2] Brazil and Venezuela, which were two countries generally believed to be most vulnerable to a currency crisis or debt default, were most affected by the Russian crisis. A graph of public debt prices displays the same pattern: the countries that had the highest probability of requiring IMF assistance soon after the Russian crisis were the countries most affected by the shock.

[INSERT FIGURE 1]

This example shows one practical problem with a fundamentals-based definition of contagion. How can we measure these fundamentals, especially in the short run? Potentially even more problematic, there is no agreement on which cross-country linkages constitute fundamentals. Does learning based on IMF behavior in Russia qualify as fundamentals? Given these significant problems, the literature on this topic has adopted several alternate, and more easily testable, definitions of contagion. One of the earliest of these definitions classifies contagion as a "shift" or change in how shocks are propagated between "normal" periods and "crisis" periods. Another common definition labels contagion as including only the transmission of crises through specific channels (such as herding or irrational-investor behavior). An even broader definition identifies contagion as any channel linking countries and causing markets to co-move. This paper focuses on the first of these three definitions (for reasons discussed in Section 3), although it frequently provides analysis and discussion based on the broader definitions. Moreover, to clarify terms and avoid any misunderstanding, this paper uses the phrase "shift-contagion" when referring to this first and narrowest definition.

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[2] Stock market indices reported by Datastream. Indices based on rolling-average, ten-day returns. Holidays and weekends are excluded. Indices normalized to 100 on August 3, 1998.

This discussion of how to define contagion is critically important for this paper's goal: to discuss and analyze contagion in Latin America during recent financial crises. Section 2 motivates the paper by examining recent patterns and correlations in bond markets and stock markets in Latin America. It finds a high degree of co-movement within Latin America and across emerging markets in general, especially in bond markets, during both crisis and non-crisis periods. Section 3 uses these trends in Latin America to discuss how contagion ought to be defined, as well as the advantages and disadvantages of alternate definitions. Section 4 briefly surveys the theoretical literature on contagion and Section 5 summarizes the econometric strategies traditionally used to test for its existence. Despite the range of strategies utilized, virtually all of this work concludes that contagion occurred during recent financial crises. Section 6, however, discusses several problems with this empirical work, namely heteroscedasticity, endogeneity, and omitted-variable bias. Tests for contagion that address these problems find little evidence of shift-contagion in Latin America during recent financial crises. Instead, these results suggest that many countries in Latin America are highly interdependent (with each other as well as the rest of the world) at all times, and these strong cross-country linkages do not change significantly during periods of crisis. Finally, section 7 concludes and discusses several policy implications for Latin America.

2. Contagion in Latin America? A First Glance

This section examines trends and relationships in bond and stock markets in Latin America. It documents how these markets were affected by the currency crises of the 1990's and measures the degree of co-movement between Latin American markets and between emerging markets in general. These comparisons provide a preliminary test for contagion and raise a number of intriguing questions.

2.1 Bond Markets in Latin America

To examine trends in Latin American bond markets, this section begins by focusing on the interest rate spread between Latin Eurobonds and the international interest rate (the stripped yield). Latin Eurobonds are mainly dollar-denominated bonds issued by governments and large firms located in Latin America. Figure 2 graphs the stripped yield of a weighted average of all Latin Eurobonds from October of 1994 to July of 1999. The figure shows that this spread between Latin Eurobonds and the international interest rate is highly volatile. For example, it fluctuated from a low of about 300 basis points during the relatively tranquil period in the third quarter of 1994, to a high of about 1600 basis points only a few months later during the Mexican peso crisis.

[INSERT FIGURE 2]

This spread between Latin Eurobonds and the international interest rate measures the average country default risk in Latin America. Then why did shocks to Hong Kong and Russia have any impact on the default risk of countries in Latin America? Are the interrelationships between Latin America and Hong Kong or Russia large? In order to answer this question, as well as to better understand how different Latin American countries are affected by regional crises (such as the 1999 Brazilian crisis), it is useful to examine the impact of each of these crises on specific bonds instead of the aggregate Latin American index.

[INSERT FIGURE 3]

Figure 3 performs this analysis. It graphs the long-term sovereign spread from January of 1997 through December of 1999 for six Latin American countries: Argentina; Brazil; Colombia; Mexico; Venezuela; and Uruguay. More specifically, these are the stripped yields on the EMBI+ index constructed by JPMorgan. These indices are mainly composed of Brady bonds, although they also include a small number of government and private dollar-denominated issues. Once again, it is immediately apparent that the risk premium for each country is highly volatile. However, the relative risk premia between countries,

(i.e. the differences in the risk premia between any two countries) are remarkably stable. For example, the risk premium on Mexican debt jumped from about 350 basis points in early 1998 to about 850 basis points during the Russian crisis. The risk premium on Argentine debt rose from about 400 to 1000 basis points over the same period. The relative risk premium between these two countries, however, was fairly stable and never rose above 125 basis points. In other words, the distance between any two lines on the graph is much more stable than any of the lines itself.

These patterns suggest that the volatility of the Latin Eurobond index (as reported in Figure 2) is not driven by movements in the risk premium for any single country or any small subset of countries. The crises in Asia and Russia increased the risk premium in all Latin American countries. Even the Brazilian crisis in 1999 affected risk premia throughout Latin America and not just in Brazil. Moreover, since each of these risk premia is stripped, this co-movement cannot be explained by movements in international interest rates. Then why is there such a high degree of co-movement in risk premia for countries that are so different? Could this be caused by a common shock to the region? To answer this question, it is useful to perform one final analysis of bond markets in Latin America: examine the correlations between bond yields in Latin America and those in other emerging markets.

Table 1 performs this analysis. It reports the cross-country correlation of stripped yields on Brady bonds from January of 1994 through December of 1999. The Latin American countries included in the table are: Argentina; Brazil; Ecuador; Mexico; Panama; Peru; and Venezuela. The other emerging markets are: Bulgaria; Morocco; Nigeria; the Philippines; Poland; and Russia. This table clearly shows that the co-movements in risk premia, as measured by stripped interest rates on Brady bonds, is extremely high for all emerging markets – not just within Latin America. The smallest cross-market correlation in the table is 80 percent. In fact, the correlation in country risk between Mexico and Morocco is 97 percent. The same number for Brazil and Bulgaria is 93 percent and for Peru and the Philippines 96 percent. Other than the fact that the names of the countries in these pairs start with the same letter of the alphabet, what else do these pairs have in common? Intuition suggests that these countries have few similarities. Then why are these markets so highly correlated over such a long period of time?

[INSERT TABLE 1]

2.2 Stock Markets in Latin America

These patterns in Latin America (and emerging markets in general) are not unique to bond markets. Movements in stock markets, exchange rates, and interest rates also show a similar set of relationships, although in most cases they are not as extreme as those for bond markets. For comparison, this section repeats the bond market analysis in Section 2.1 for stock markets.

Figure 4 begins by graphing an aggregate index for stock markets in Latin America. This index is a weighted average of the daily stock market indices in U.S. dollars reported by DataStream.[3] The countries included in the index are: Argentina; Brazil; Chile; Colombia; Mexico; Peru; and Venezuela. The figure shares a number of features with Figure 2 (which graphs the spread between the Latin Eurobond index and international interest rates.) Latin American stock and bond indices are both highly volatile and are adversely affected by events in the rest of the world. For example, the aggregate Latin American stock market index falls from a high of about 140 before the Asian crisis to a low of about 60 after the Russian crisis. The index is not nearly as vulnerable to shocks that originate within Latin America as to shocks external to the region. For example, the index only falls from about 100 to 75 during the Brazilian crisis. Why do crises external to Latin America have such a disproportionately large impact on the region?

[INSERT FIGURE 4]

Next, Figure 5 breaks this aggregate Latin American stock market index into its component parts. This figure graphs the stock market index for each of the seven Latin American countries forming the

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[3] More specifically, these indices are ten-day, rolling-average, demeaned returns. Weights for each country are calculated as the standard deviation for that country relative to the average standard deviation for the sample.

aggregate index in Figure 4.[4] Figure 5 shows that stock markets in most Latin American countries are highly volatile, and that during recent currency crises stock markets in this region tend to move together.[5] Although this co-movement is not as extreme as seen in Figure 3 for Brady bonds, these patterns are still intriguing. Why is there such a high degree of correlation between such different Latin American countries?

[INSERT FIGURE 5]

The final step in this analysis is to calculate the correlation between Latin American stock markets and those in other emerging markets. Table 2 calculates these correlations from January of 1994 through December of 1999 for seven Latin American countries (Argentina, Brazil, Chile, Ecuador, Mexico, Peru, and Venezuela) and six other emerging markets (Egypt, Hungary, Morocco, the Philippines, Poland, and Russia).[6] This table shows that co-movements in stock returns are high for a number of emerging markets – not just for stock markets within Latin America. The cross-market correlation between Argentina and Brazil is 78 percent. This is not surprising since these two markets are closely linked through channels such as trade. Less intuitive, however, is the cross-market correlation between Argentina and Hungary – which is also 78 percent. What do these two markets have in common? Similarly, why are stock markets in Peru and Russia correlated by 75 percent? And in Brazil and Egypt by 80 percent? Intuition suggests that these countries have few similarities.

[INSERT TABLE 2]

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[4] Indices continue to be ten-day, rolling- average, demeaned, daily, U.S. dollar returns as reported by Datastream. The indices are normalized to 100 on October 1, 1994.

[5] In fact, the variance of the relative valuations between Latin American countries is one-tenth of the variance of the individual stock market returns.

[6] More specifically, this table reports the cross-market correlations in weekly U.S. dollar stock market indices as calculated by Datastream. The countries in this table are slightly different than those in the table for bond markets because several countries used in the previous table do not have stock market data.

2.3 Conclusions: Bond and Stock Markets in Latin America

This examination of Latin American bond and stock markets has generated a number of patterns and questions. Each of these patterns is strongest in bond markets, but is also true for stock markets, exchange rates, and interest rates. We begin with the patterns. First, stripped bond spreads and stock returns in Latin America are highly volatile and this volatility is largely driven by external events, such as the Asian and Russian crises. Second, this volatility is not generated by any individual country or subset of countries within Latin America, but instead is shared by all countries in the region. In other words, the relative risk premia and stock returns between countries are fairly stable. Third and finally, this co-movement in risk premia and stock returns is high between many emerging markets, not just between countries in Latin America. This series of patterns has generated a number of questions. First, why are risk premia and stock returns in Latin America so significantly affected by events outside of the region? Second, why do risk premia and stock returns across such diverse Latin American countries show such a high degree of co-movement? Third and closely related, why are movements in bond and stock markets so highly correlated in emerging markets around the world?

3. Defining Contagion

The previous section documented a high degree of co-movement in Latin American bond and stock markets. It also discussed the high correlation between very diverse emerging markets around the world. But is this high degree of co-movement evidence of contagion? And what are the policy implications of these strong cross-market relationships? Before attempting to answer these questions, it is necessary to define exactly what constitutes contagion.

As mentioned in the introduction, in the month after the 1998 devaluation of the Russian ruble, the Brazilian stock market fell by over 50 percent. Even without a precise definition, most people would agree that this transmission of a shock from Russia to Brazil was contagion. On January 13, 1999 the Brazilian

stock market crashed by about 13 percent and the Argentine stock market fell by about 9 percent. Then one day later the Brazilian market rose by about 23 percent and the Argentine market recovered by about 11 percent. Did these events constitute contagion? Or if the U.S. stock market crashes and this has a significant impact on the Mexican market, is this considered contagion?

These sorts of examples show the difficulty in defining contagion. This paper defines contagion as a significant increase in cross-market linkages after a shock to an individual country (or group of countries). This was the most common definition of financial contagion before the crises of the late 1990's. Since then a number of additional definitions have been proposed, although there is little consensus on which definition should be utilized. This paper uses the phrase "shift-contagion" instead of simply "contagion" in order to differentiate this precise definition from the numerous other definitions that currently exist. The term shift-contagion is sensible because it not only clarifies that contagion arises from a shift in cross-market linkages, but it also avoids taking a stance on how this shift occurred. Cross-market linkages can be measured by a number of different statistics, such as: the correlation in asset returns; the probability of a speculative attack; or the transmission of shocks or volatility.

This definition of contagion has a number of advantages. First, it is empirically useful since it easily translates into a simple test for contagion (by testing if cross-market linkages change significantly after a shock). Second, it is extremely valuable in drawing policy conclusions, a topic is discussed in more detail in Section 7. Third and finally, this definition is appealing based on our intuition and preconceptions of what constitutes contagion. For example, as mentioned above the Argentine stock market fell and rose with the Brazilian market during the crisis of January 1999. When Brazil initially abandoned its peg during this period, what did we predict would happen to Argentina? Brazil and Argentina are located in the same geographic region, have many similarities in terms of market structure and history, and have strong direct linkages through trade and finance. These two economies are closely connected in all states of the world. Therefore, it is not surprising that a large negative shock to one country is quickly passed on to the other. If this transmission of a shock from Brazil to Argentina is a continuation of the same cross-market linkages

that exist during more tranquil periods (and not a shift in these linkages) then this should not be considered shift-contagion.

It is important to note, however, that this definition of contagion is not universally accepted. Some economists argue that if a shock to one country is transmitted to another country, even if there is no significant change in cross-market relationships, this transmission constitutes contagion. In the example above, the impact of a U.S. stock market crash on the Mexican market would be considered contagion. Other economists argue that it is impossible to define contagion based on simple tests of changes in cross-market relationships. Instead, they argue that it is necessary to identify exactly how a shock is propagated across countries, and that only certain types of transmission mechanisms (such as herding or irrational-investor behavior) constitute contagion.

These broader definitions of contagion also have several advantages. For example, intuition suggests that Mexico and Morocco have little in common. These countries are located in different regions of the world, have very different market structures and histories, and have few direct linkages through trade or finance. In other words, there are few fundamental linkages between these two nations. Therefore, according to these broader definitions of contagion, if a shock to Mexico has a significant impact on Morocco, this would qualify as contagion. In Section 2, however, we saw that the correlation in country risk between Mexico and Morocco (as measured by stripped interest rates on Brady bonds) was 97 percent. Even if this cross-market correlation remains constant, a shock to Mexico would have a significant impact on the risk premium in Morocco. Therefore, according to the stricter definition of contagion used in this paper, this transmission of a shock from Mexico to Morocco would not qualify as shift-contagion. Yet even if this is not an example of shift-contagion, it is obviously puzzling that these two markets are so highly correlated in any state of the world. In order to discuss this puzzle and differentiate it from the concept of shift-contagion, this paper uses the term "interdependence" to describe this scenario. In other words, interdependence describes situations when countries show a higher degree of co-movement in all states of the world than can be explained by fundamentals.

To summarize, this paper defines contagion as a significant increase in cross-market linkages after a shock. This definition implies that if two markets are highly correlated after a crisis, this is not necessarily contagion. It is only shift-contagion if the correlation between the two markets increases significantly. Agreement with this definition is not universal, but it does concur with our intuitive understanding of contagion, as well as provide a straightforward method of testing for the existence of contagion.

4. Theoretical Literature

The theoretical literature on how shocks are propagated internationally is extensive and has been well summarized in a number of other papers.[7] For the purpose of this paper, however, it is useful to divide this broad set of theories into two groups: crisis-contingent and non-crisis-contingent theories. Crisis-contingent theories are those which explain why transmission mechanisms change during a crisis and therefore why cross-market linkages increase after a shock. Non-crisis-contingent theories assume that transmission mechanisms are the same during a crisis as during more stable periods, and therefore cross-market linkages do not increase after a shock. As a result, evidence of shift-contagion would support the group of crisis-contingent theories, while no evidence of contagion would support the group of non-crisis-contingent theories.

4.1 Crisis-Contingent Theories

Crisis-contingent theories of how shocks are transmitted internationally can be divided into three mechanisms: multiple equilibria; endogenous liquidity; and political economy. The first mechanism, multiple equilibria, occurs when a crisis in one country is used as a sunspot for other countries. For example, Masson (1998) shows how a crisis in one country could coordinate investors' expectations, shifting them from a good to a bad equilibrium for another economy and thereby cause a crash in the second economy.

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[7] For example, see Claessens, Dornbusch and Park (2001) and Forbes (2000a).

Mullainathan (1998) argues that investors imperfectly recall past events. A crisis in one country could trigger a memory of past crises, which would cause investors to recompute their priors (on variables such as debt default) and assign a higher probability to a bad state. The resulting downward co-movement in prices would occur because memories (instead of fundamentals) are correlated. In both of these models, the shift from a good to bad equilibrium and the transmission of the initial shock is therefore driven by a change in investors' expectations or beliefs and not by any real linkages. This branch of theories can not only explain the bunching of crises, but also why speculative attacks occur in economies that appear to be fundamentally sound.[8] These qualify as crisis-contingent theories because the change in the price of the second market (relative to the change in the price of the first) is exacerbated during the shift between equilibria. In other words, after the crisis in the first economy, investors change their expectations and therefore transmit the shock through a propagation mechanism that does not exist during stable periods.

A second category of crisis-contingent theories is endogenous liquidity shocks. Valdés (1996) develops a model where a crisis in one country can reduce the liquidity of market participants. This could force investors to recompose their portfolio and sell assets in other countries in order to continue operating in the market, to satisfy margin calls, or to meet regulatory requirements. Similarly, if the liquidity shock is large enough, a crisis in one country could increase the degree of credit rationing and force investors to sell their holdings of assets in countries not affected by the initial crisis. Calvo (1999) develops another model of endogenous liquidity. In Calvo's model, there is asymmetric information among investors. Informed investors receive signals about the fundamentals of a country and are hit by liquidity shocks (margin calls) that force the informed investors to sell their holdings. Uninformed investors cannot distinguish between a liquidity shock and a bad signal, and therefore charge a premium when the informed investors are net sellers. In both of these models, the liquidity shock leads to an increased correlation in asset prices. This transmission mechanism does not occur during stable periods and only occurs after the initial shock.

A final transmission mechanism that can be categorized as a crisis-contingent theory is political contagion. Drazen (1998) studies the European devaluations in 1992-3 and develops a model that assumes

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[8] This point has been raised by Radelet and Sachs (1998) and Sachs, Tornell and Velasco (1996).

that central bank presidents are under political pressure to maintain their countries' fixed exchange rates. When one country decides to abandon its peg, this reduces the political costs to other countries of abandoning their respective pegs, which increases the likelihood of these countries switching exchange rate regimes. As a result, exchange rate crises may be bunched together. Once again, transmission of the shock occurs through a mechanism that did not exist before the initial crisis.

This group of crisis-contingent theories suggests a number of very different channels through which shocks could be transmitted internationally: multiple equilibria based on investor psychology; endogenous-liquidity shocks causing a portfolio recomposition; and political economy affecting exchange rate regimes. Despite the different approaches and models used to develop these theories, they all share one critical implication: the transmission mechanism during (or directly after) the crisis is inherently different than any which exist before the shock. The crisis causes a structural shift, so that shocks are propagated via a channel that does not operate in stable periods. Therefore, each of these theories could explain the existence of contagion as defined in Section 3.

4.2 Non-Crisis-Contingent Theories

On the other hand, the remainder of theories explaining how shocks could be propagated internationally would not generate shift-contagion. These theories assume that transmission mechanisms after an initial shock are not significantly different than before the crisis. Instead, any large cross-market correlations after a shock are a continuation of linkages that exist before the crisis. These channels are often called "real linkages" since many (although not all) are based on economic fundamentals. These theories can be divided into four broad channels: trade; policy coordination; country reevaluation; and random aggregate shocks.

The first transmission mechanism, trade, could work through several related effects.[9] If one country devalues its currency, this would have the direct effect of increasing the competitiveness of that country's

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[9] Gerlach and Smets (1995) first developed this theory with respect to bilateral trade and Corsetti, Pesenti, Roubini and Tille (2000) used micro-foundations to extend this to competition in third markets. For empirical tests of the

goods, potentially increasing exports to a second country and hurting domestic sales within the second country. The initial devaluation could also have the indirect effect of reducing export sales from other countries that compete in the same third markets. Either of these effects could not only have a direct impact on a country's sales and output, but if the loss in competitiveness is severe enough, it could increase expectations of an exchange rate devaluation and/or lead to an attack on another country's currency.

The second non-crisis-contingent transmission mechanism is policy coordination. This mechanism links economies because one country's response to an economic shock could force another country to adopt certain policies. For example, a trade agreement might include a clause in which lax monetary policy in one country forces other member countries to raise trade barriers.

The third propagation mechanism, country reevaluation or learning, argues that investors may apply the lessons learned after a shock to one country to other countries with similar macroeconomic structures and policies.[10] For example, if a country with a weak banking system is discovered to be vulnerable to a currency crisis, investors could reevaluate the strength of banking systems in other countries and adjust their expected probabilities of a crisis accordingly.

The final non-crisis-contingent transmission mechanism argues that random aggregate or global shocks could simultaneously affect the fundamentals of several economies. For example, a rise in the international interest rate, a contraction in the international supply of capital, or a decline in international demand (such as for commodities) could simultaneously slow growth in a number of countries. Asset prices in any countries affected by this aggregate shock would move together (at least to some degree), so that directly after the shock, cross-market correlations between affected countries could increase.

5. Empirical Evidence: Contagion Exists

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importance of trade, see Eichengreen, Rose and Wypolsz (1996), Glick and Rose (2000), Forbes (2000a), and Forbes (2000b).

[10] This includes models of herding and informational cascades, such as Chari and Kehoe (1999) and Calvo and Mendoza (1998).

The empirical literature testing if contagion exists is even more extensive than the theoretical literature explaining how shocks can be transmitted across countries. Since this literature is so extensive and has been well summarized elsewhere, this paper does not attempt to survey this work.[11] Instead, it simply describes the four general strategies used to test for contagion and the essence of each strategy's findings. Many of these empirical tests use the same definition of contagion as specified in Section 3, although some of the more recent work uses a broader or less well-specified definition. The key point of this review is that virtually all of the previous work on this topic has concluded that contagion − no matter how it is defined or tested for − occurred during the crisis under investigation.

The most common strategy to test for contagion is based on cross-market correlation coefficients. These tests measure the correlation in returns between two markets during a stable period and then test for a significant increase in this correlation coefficient after a shock. If the correlation coefficient increases significantly, this suggests that the transmission mechanism between the two markets increased after the shock and contagion occurred. Virtually all papers using this testing strategy reach the same general conclusion: cross-market correlation coefficients increase significantly (at least for some countries) after a currency crisis. Therefore, contagion occurred during the period under investigation.

A second approach to test for contagion is to use an ARCH or GARCH framework to estimate the variance-covariance transmission mechanisms across countries. These tests generally indicate that volatility was transmitted from one country to the other. A third testing strategy uses simplifying assumptions and exogenous events to identify a model and directly measure changes in the propagation mechanism. These papers generally find that a crisis in another country or news in another country increased the probability of a crisis occurring elsewhere in the world (and especially in the same region).

A final series of tests for contagion focus on changes in the long-run relationship between markets instead of on any short-run changes after a shock. These papers use the same basic procedures as above, except that they test for changes in the co-integrating vectors between stock markets instead of in the

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[11] For detailed surveys of empirical tests for contagion, see Forbes and Rigobon (2001), Baig and Goldfajn (1998), and Claessens, Dornbusch, and Park (2001). For tests of contagion covering periods from the Debt crisis of 1982 through the Asian crisis, see De Gregorio and Valdés (2001).

correlation coefficients or variance-covariance matrices. This approach is not an accurate test for contagion, however, since it assumes that real linkages between markets (i.e. the non-crisis-contingent theories such as trade) remain constant over the entire period. If tests show that the co-integrating relationship increases over time, this could be a permanent shift in cross-market linkages instead of contagion. Moreover, by focusing on such long time periods, this set of tests could miss brief periods of contagion (such as after the Russian collapse of 1998).

      To summarize, a variety of different econometric techniques have been used to test if contagion occurred during a number of financial and currency crises. The transmission of shocks has been measured by cross-market correlation coefficients, GARCH models, probit models, and cointegration techniques. The cointegration analysis is not an accurate test for contagion due to the long time periods under consideration. Results based on the other techniques, however, all arrive at the same general conclusion: contagion occurred. The consistency of this finding is remarkable given the range of techniques utilized and periods investigated.

6. Contagion Reinterpreted as Interdependence

      Although the tests for contagion described above appear straightforward, they may be biased in the presence of heteroscedasticity, endogeneity, and omitted variables. This section begins with a coin example to show how heteroscedasticity can affect tests for contagion. It then presents a simple model to clarify exactly how heteroscedasticity, endogeneity and omitted variables could bias estimates of the transmission of shocks. The section concludes with an overview of recent empirical work that has corrected for each of these problems and found that virtually no contagion occurred during recent financial crises. These studies show that large cross-market linkages after a shock are simply a continuation of strong transmission mechanisms that exist in more stable periods. We refer to these strong transmission mechanisms that exist in

all states of the world as interdependence, in order to contrast these linkages with new transmission mechanisms that occur only during crisis periods (i.e. shift-contagion).

6.1 A Coin Example: The Effect of Heteroscedasticity on Tests for Contagion

A coin-flipping exercise provides a simple example of how heteroscedasticity can bias the standard approach tests for changes in cross-country transmission mechanisms after a crisis. Suppose that there are two related games. In the first game you flip one coin. If it is heads, you win the coin, and if it is tails, you lose the coin. The game can be played with either a penny or a special $100 coin. In the second game, you also flip a coin and win with heads or lose with tails. Now, however, the coin is always a quarter. The payoff after the second game depends on the outcome of the first game. For simplicity, assume that the payoff is always ten percent of the outcome of the first game plus the outcome of the second game. Therefore, if the first game is played with a penny, the possible payoffs (in cents) after both games have been played are:

[INSERT TABLE 3]

Since the final payoff is equal to the outcome of the second game (25 cents) plus or minus a tenth of a penny, the outcome of the first coin toss has a negligible impact on the payoff. Therefore, when the first game is played with a penny, the correlation between the two games is close to zero (0.4 percent, to be exact) and the outcomes of the two games are almost independent.

On the other hand, when the first game is played with a $100 coin instead of a penny, the possible payoffs are (again in cents):

[INSERT TABLE 4]

The final payoff is now equal to the 25 cent outcome of the second game plus or minus ten dollars. In this case, the outcome of the second toss, instead of the first, has a negligible impact on the payoff. The

correlation between the two games is now almost one (97 percent) and the outcomes of the two games are clearly dependent on each other.

The critical point of this exercise is that in both the one cent and the $100 dollar scenario, the propagation of shocks from the first game to the second is always ten percent. The correlation coefficient, however, increases from almost zero in the one-cent scenario to almost one in the $100 scenario. Moreover, this coin example is directly applicable to measuring the transmission of shocks across countries. The first coin toss represents a country that is susceptible to a crisis. When the country is stable, volatility is low, which is the scenario when the first game is played with a penny. When the economy becomes more vulnerable to a crisis, volatility increases, which is the scenario when the first game is played with the $100 coin. The crisis actually occurs when the outcome of the $100 coin is tails. The second toss represents the rest of the world; this round is always played with a quarter, but the payoff depends on the outcome in the first country. As the coin example clearly shows, even though the underlying transmission mechanism remains constant (at 10 percent) in both states, the cross-market correlation in returns increases significantly after the crisis. As a result, tests for contagion based on correlation coefficients would suggest that shift-contagion occurred, even though there was no fundamental change in how shocks are propagated across markets. Tests for contagion based on GARCH models are subject to the same bias, since the variance-covariance matrices central to these tests are directly comparable to the correlation coefficients. In both of these types of tests, this inaccurate finding of contagion results from the heteroscedasticity in returns across the two different states (i.e. the two different coins for the first toss.)

Heteroscedasticity will also bias tests for contagion that use probit models or conditional probabilities, although this bias works through a slightly different mechanism. A minor variant on the coin game shows how the bias occurs with these testing methodologies. Assume that now you are only interested in knowing if the payoff from the previous game is positive (labeled as one) or negative (labeled as zero). The restated outcomes of the game are:

[INSERT TABLE 5]

A probit regression estimating how the outcome of the first game (i.e. the state of the first country) affects the probability of the outcome in the second game (i.e. the payoff in the second country) could be written:

$$\Pr[y_t > 0] = \gamma \Pr[x_t > 0]$$

The table shows that $\gamma = 0$ when the first toss is done with a penny (i.e. the first economy is stable), but $\gamma = 1$ when the first toss is done with the $100 coin (i.e. the economy is more volatile).[12] As a result, tests for contagion would suggest that the magnitude of the transmission mechanism increased. The underlying transmission mechanism between the two economies, however, remained constant at 10 percent in both states so that the finding of shift-contagion is erroneous. Once again, the underlying bias results from the heteroscedasticity in returns across the two different states.

A slightly different way of interpreting these results and the impact of heteroscedasticity on tests for contagion is to reframe the last coin game in terms of conditional probabilities. Before the game starts, if you do not know which coin is being used (i.e. what state the country is in) then the probability that the outcome is negative at the end of the two tosses is 1/2. This is the unconditional probability of a negative final outcome (i.e. of a crisis in the second country). On the other hand, if you use the $100 coin and the outcome of the first toss is tails (i.e. the first country is in a crisis) then the probability that the final outcome is negative is 1. This is the conditional probability of a negative final outcome. When we compare cross-market relationships after a crisis, we are implicitly testing for an increase from the unconditional to the conditional probability, and as shown in this example, this probability can increase when only the variance increases. An increase in this probability does not necessarily indicate a change in the propagation mechanism. Therefore, tests for contagion after a crisis, which are conditional probabilities by definition, will be biased and can incorrectly suggest that contagion occurred.

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[12] This fact that heteroscedasticity biases coefficient estimates in non-linear regressions is well known. See Horowitz (1992, 1993) and Manski (1975, 1985).

This series of examples based on coin tosses is clearly a simplification of the real-world transmission of shocks across countries. Moreover, the example is extreme since the variance of outcomes increases by 10^8 when the fictionary country moves from the stable to the volatile state (i.e. when we switch coins in the first coin toss). Despite this simplification, the point of the exercise is clear. Tests for contagion in the presence of heteroscedasticity are inaccurate. No matter which of the testing procedures is utilized, heteroscedasticity will bias the results toward finding contagion, even when the underlying propagation mechanism is constant and no shift-contagion actually occurred.

6.2 A Model: The Effects of Heteroscedasticity, Endogeneity and Omitted Variables on Tests for Contagion

Beside heteroscedasticity, two other problems with the standard tests for contagion are endogeneity and omitted variables. A simple model clarifies how all three of these problems can bias tests for changes in cross-market transmission mechanisms. Assume that there are two countries whose stock market returns are x_t and y_t and which are described by the following model:

$$y_t = \beta x_t + \gamma z_t + \varepsilon_t \tag{1}$$
$$x_t = \alpha y_t + z_t + \eta_t \tag{2}$$
$$E[\eta_t' \varepsilon_t] = 0, \quad E[z_t' \varepsilon_t] = 0, \quad E[z_t' \eta_t] = 0, \tag{3}$$
$$E[\varepsilon_t' \varepsilon_t] = \sigma_{\varepsilon_t}^2, \quad E[\eta_t' \eta_t] = \sigma_{\eta_t}^2, \quad E[z_t' z_t] = \sigma_{z_t}^2, \tag{4}$$

where ε_t and η_t are country-specific shocks that are assumed to be independent but are not necessarily identically distributed. Also, without loss of generality, assume that the returns have mean zero. Unobservable aggregate shocks, such as changes in global demand, exogenous liquidity shocks, or changes in the international interest rate, are captured by z_t (which has been normalized for simplicity) and affect

both countries. Note that z_t is assumed to be independent of x_t and y_t.[13] Since shocks are transmitted across countries through real linkages, the stock markets are expected to be endogenous variables (α, $\beta \neq 0$). Finally, it is worth noting that the variance of the idiosyncratic shocks changes through time to reflect the heteroscedasticity discussed above.

Tests for contagion estimate if the propagation mechanisms (α, β, or γ) change significantly during a crisis. Forbes and Rigobon (1999) present a proof that shows that heteroscedasticity in market returns can have a significant impact on estimates of cross-market correlations. For any distribution of the error terms, when market volatility increases after a crisis, the unadjusted correlation coefficient will be biased upward.[14] In fact, this unadjusted correlation coefficient is an increasing function of the market variance. The intuition behind this bias is the same as in the coin example of Section 6.1. If the variance of x_t goes to zero in equation (1), then all of the innovations in y_t are explained by its idiosyncratic shock (ε_t), and the correlation between x_t and y_t is zero. On the other hand, if x_t experiences a shock and its variance increases, then a greater proportion of the fluctuation in y_t is explained by x_t. In the limit, when the variance of x_t is so large that the innovations in ε_t are negligible, then all of the fluctuations in y_t are explained by x_t, and the cross-market correlation will approach one. Basically, changes in the relative variance of the two shocks modify the noise/signal ratio and biases correlation estimates. The critical point, however, is that the propagation (β) between x_t and y_t remains constant. Since there is no significant change in how shocks are transmitted across markets, no contagion occurred. Moreover, since the correlation coefficient is biased upward after a shock, tests could incorrectly conclude that the propagation mechanism increased and contagion occurred.

In addition to heteroscedasticity, another problem with this simple model is endogeneity. Equations (1) and (2) are clearly endogenous, and it is impossible to identify these equations and estimate the coefficients directly. For example, in tests based on correlation coefficients or GARCH models, there is no way to differentiate between shifts in the coefficients or shifts in the variances (i.e. heteroscedasticity).

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[13] It is possible to drop this assumption by interpreting equations (1) and (2) as reduced forms and expressing z_t as an innovation in a third equation.

[14] Ronn (1998) presents a proof for the special case in which the errors are distributed as bivariate normal.

A final problem with this model is omitted variables. When the variance of z_t increases, the cross-market correlations are biased in the same way as when the variance of x_t increases (as discussed above). When the variance of the aggregate shock is larger, the relative importance of the component common to both markets grows, and the correlation between the two markets increases in absolute value. Since unobservable aggregate shocks, as well as the stock price in the other market, would both be omitted variables, this bias is likely to be large and can have a significant impact on tests for contagion.

6.3 Tests For Contagion: Adjusting for Heteroscedasticity, Endogeneity and Omitted Variables

Unfortunately, it is impossible to adjust for heteroscedasticity, endogeneity, and omitted variables in the model of Equations 2 through 4 without making more restrictive assumptions or utilizing additional information. Nevertheless, several papers have tried to correct for one or more of these problems and explore how these corrections affect tests for contagion. This section summarizes a number of papers that have used a variety of different approaches, identification assumptions, and model specifications to adjust for one (or more) of these problems. Each paper finds that transmission mechanisms were fairly stable during recent financial crises, and since contagion is defined as a significant increase in cross-market linkages after a shock, this suggests that little shift-contagion occurred during these crises.

In the first paper to address the problem of heteroscedasticity in tests for contagion, Forbes and Rigobon (1999) simplify the above model by assuming that there is no feedback from stock market y_t to x_t (i.e. that $\alpha = 0$). They also begin by assuming that there are no exogenous global shocks (i.e. that $z_t = 0$). Both of these assumptions are possible based on what the literature calls near-identification. In their paper, x_t is always the country under crisis, and the variance of returns in the crisis countries increases by more than 10 times during their respective collapses. As a result, it is realistic to assume that the entire shift in the variances is due to the change in the volatility of the idiosyncratic shock of country x_t. This means that, at least during the crises, the contribution of the other two shocks (the aggregate shock z_t, and the other country

shock η_t) is negligible. Therefore, during the period under examination, any bias from endogeneity and omitted variables should be small.

After establishing this framework, Forbes and Rigobon (1999) extend the proof from Ronn (1998) for the case of a general distribution function for the error terms. They show why the unadjusted correlation coefficient is biased upward after a shock and describe a simple technique for adjusting for this bias.[15] Basically, they calculate both the conditional correlation, ρ^c_t, (i.e. the unadjusted correlation coefficient) and the relative increase in the conditional variance in the crisis country (δ). Then they use equation 5 to calculate the unconditional correlation coefficient, ρ_t, and compare it with the cross-market correlation in returns during the tranquil months prior to the crisis.[16]

$$\rho_t = \frac{\rho^c_t}{\sqrt{1 + \delta_t\left[1 - \left(\rho^c_t\right)^2\right]}} \qquad (5)$$

A simple graph clarifies the intuition behind this adjustment and why it can have a significant impact on tests for contagion. Figure 6 graphs the correlation in stock market returns between Hong Kong and the Philippines during 1997.[17] The dashed line is the unadjusted (or conditional) correlation in daily returns (ρ^c_t), and the solid line is the adjusted (or unconditional) correlation (ρ_t). While the two lines tend to move up and down together, the bias generated by changes in market volatility (i.e. heteroscedasticity) is clearly significant. During the relatively stable period in the first half of 1997, the unadjusted correlation is always lower than the adjusted correlation. On the other hand, during the relatively tumultuous period of the fourth quarter, the unadjusted correlation is significantly greater than the adjusted correlation. Tests based on

[15] The basis for this adjustment was proposed by Rob Stambaugh in a discussion of Karolyi and Stulz (1995) at the May NBER Conference on Financial Risk Assessment and Management. In the mathematical literature, the oldest reference we have found is Liptser and Shiriaev (1977), chapter 13, which refers to this adjustment as the theorem on normal correlation.

[16] The derivation of equation 5 assumes that there is no endogeneity or omitted-variables bias.

[17] Correlations are calculated as quarterly moving averages. The procedure, definitions, and data source used to estimate this graph are described in Forbes and Rigobon (1999).

the unadjusted correlations would find a significant increase in cross-market correlations in the fourth quarter and would therefore indicate contagion. On the other hand, the adjusted correlations do not increase by nearly as much, so a test based on these unconditional correlations might not suggest contagion.

[INSERT FIGURE 6]

Forbes and Rigobon then perform an extensive set of tests for shift-contagion based on both the unadjusted and adjusted correlation coefficients. They use daily data for a variety of developed and emerging market stock indices (up to 28 countries) and test for contagion during three periods of market turmoil: the 1987 U.S. stock market crash, the 1994 Mexican peso collapse, and the 1997 East Asian crisis. In each case, they test for a significant increase in the cross-market correlation coefficient between a long, stable period before the crisis and the period directly after the crisis. They also control for a variety of other variables, such as lagged stock market returns and interest rates in the two relevant countries and the U.S. Results are striking. Tests based on the unadjusted correlation coefficients find evidence of contagion in a significant number of countries – about 50 percent of the sample during the Asian crisis and U.S. crash and about 20 percent of the sample after the Mexican collapse. Moreover, during the Mexican crisis most of the significant changes occur with Latin American countries.

When the same tests are based on the adjusted correlation coefficients, however, the incidence of contagion falls dramatically – to zero in most cases. An extensive sensitivity analysis evaluates the impact of: adjusting the frequency of returns and lag structure; modifying period definitions; altering the source of contagion; varying the interest rate controls; and utilizing returns denominated in local currency instead of dollars. In each case, the central result does not change (although the exact number of cases of contagion is highly dependent on the specification estimated.) Forbes and Rigobon conclude that when contagion is defined as a significant increase in cross-market relationships and correlation coefficients are adjusted for

heteroscedasticity, there was virtually no contagion during the 1987 U.S. stock market crash, the 1994 Mexican Tequila crisis, and the 1997 East Asian crisis.

Lomakin and Paiz (1999) make the same simplifying assumptions as Forbes and Rigobon (1999) to address this problem of heteroscedasticity in tests for contagion in bond markets. Instead of testing for a significant change in cross-market correlation coefficients, however, Lomakin and Paiz use a probit analysis to compute the likelihood that one country will have a crisis given that another country has already experienced one. They study Brady countries, so that their data set is mainly comprised of Latin American economies. They show that estimates of this probability will be biased in the presence of heteroscedasticity, and that it is impossible to identify the direction of this bias. Although this paper is still a work in progress, preliminary results suggest that adjusting for heteroscedasticity can have a significant impact on defining the threshold used to identify crisis periods. When they use the adjustment proposed in Forbes and Rigobon to correct the variance-covariance matrices, the number of crises and the strength of cross-country linkages are both reduced significantly.

Rigobon (1999) makes a different set of simplifying assumptions in order to directly identify his tests for contagion. These assumptions not only solve for endogeneity, but are also valid in the presence of heteroscedasticity and omitted variables. Rigobon's key assumption is that during a crisis the variance of the disturbances increases in only one market. Using this, he develops a test where the joint null hypothesis is that only one of the variances of the structural shocks increases and the transmission mechanism is stable. The test is therefore rejected if either the transmission mechanism changes (i.e. contagion occurs) or if the variances of two or more disturbances increase. Rigobon then uses this methodology to test if the cross-country propagation of shocks is fairly stable between stock markets during the Mexican, East Asian, and Russian crises. He estimates the same basic model as in Forbes and Rigobon (1999) and tests for a significant change in transmission mechanisms between the stable period before each crisis and the tumultuous period directly after each crisis. In tests for contagion within one month of each crisis, he finds that transmission mechanisms increase significantly in less than 15 percent of the cross-country pairs (and in less than 7 percent during the Mexican crisis.) A sensitivity analysis indicates that model specification can

affect results, but in most cases when the results change significantly, there is more than one crisis during the tumultuous period (which increases the chance of the test being rejected). Rigobon concludes that transmission mechanisms were fairly stable and that shift-contagion occurred in less than 10 percent of the stock markets during recent financial crises. Arias, Hausmann and Rigobon (1999) extend this analysis to test for the existence of shift-contagion in sovereign bond markets. They find that cross-country relationships are stable during the currency crises in Mexico, Thailand, Hong Kong and Korea, and only increase significantly between Argentina and Brazil during the Russian crisis.

Finally, Rigobon (2000) proposes a new methodology that uses heteroscedasticity to identify parameters when the model and data suffer from omitted-variable bias and endogeneity. Under certain conditions this methodology can be used to test for the stability of parameters across periods and can therefore indicate if shift-contagion occurred. Details of this test are described in more detail in the appendix. Using this procedure, Rigobon finds that the relationship between Brady bonds in Argentina and Mexico was stable between 1994 and 1999, indicating that shift-contagion did not occur during this period between these two markets.

In summary, shift-contagion in stock and sovereign-bond markets has been extensively studied in the literature. Tests for parameter stability have been performed for a number of different frequencies and base currencies, using a variety of different methodologies and econometric techniques. These tests have also been performed for a range of periods, extending from the Debt crisis in 1982 to the Brazilian crisis in 1999. Without exception, papers which use tests that do not adjust for heteroscedasticity find important regime changes that indicate that shift-contagion occurred. In the particular case of Latin America, unadjusted tests consistently find evidence of shift-contagion within this region during the Debt crisis in 1982 and the Tequila crisis in 1994.

As argued above, however, these tests are misspecified when the data exhibits heteroscedasticity, simultaneity, and omitted-variable bias. When tests for structural change use procedures that adjust for these problems, there is minimal evidence of parameter instability. For example, the relationship between Mexico and Argentina has been subject to profound scrutiny in the literature. Stock market returns, sovereign bonds,

and domestic interest rates of these two countries have been analyzed in very different samples and frequencies. When robust techniques are used to analyze cross-market relationships, tests are usually unable to reject the hypothesis that propagation mechanisms between these two countries were stable between tranquil periods and crises.

7. Conclusions and Policy Implications

This survey of recent empirical work testing for contagion makes several critical points. First, tests for contagion that do not correct for heteroscedasticity are biased. When market volatility increases, which tends to happen during crises, these tests will overstate the magnitude of cross-market relationships. As a result, tests for contagion that do not adjust for heteroscedasticity may suggest that contagion occurred, even when cross-market transmission mechanisms were stable and shift-contagion did not occur.

Second, each of the papers that has attempted to correct for heteroscedasticity, endogeneity and/or omitted variables has shown that the bias from these problems is significant and will affect estimates of contagion during recent financial crises. These papers use a variety of different approaches, identification assumptions, and model specifications to adjust for one (or more) of these problems. They find that transmission mechanisms were fairly stable during recent financial crises, and since contagion is defined as a significant increase in cross-market linkages after a shock, this suggests that little contagion occurred during these crises.

Third and finally, these empirical papers find that, even though cross-market linkages do not increase significantly after a shock, these linkages are surprisingly high in all states of the world. In other words, strong transmission mechanisms after a shock are a continuation of strong linkages that exist during stable periods. In order to differentiate this situation from shift-contagion, Forbes and Rigobon (1999) refer to the existence of strong transmission mechanisms in all states of the world as "excess interdependence".

Therefore, recent empirical work that adjusts for heteroscedasticity, endogeneity, and/or omitted variables finds "no contagion, only interdependence."

These key results are not surprising in light of the analysis of Latin American bond and stock markets. Section 2 showed that the co-movement in risk premia and stock returns was surprisingly high for countries within Latin America. These co-movements were also high for a range of emerging markets around the world. This high degree of co-movement over long periods of time reflects this empirical finding of "excess interdependence." Similarly, Section 2 presented two graphs that showed that although Latin American countries were extremely vulnerable to events outside of the region, relative risk premia and relative stock returns between countries were fairly stable. In other words, cross-market relationships appeared fairly constant during crisis and non-crisis periods. This supports the empirical finding of "no contagion" when contagion is defined as a shift in cross-market linkages.

These central results also have a number of important policy implications for Latin America. One motivation for this extensive literature on contagion is to better understand how to reduce a country's vulnerability to external shocks. If crises are transmitted largely through temporary channels that only exist after a crisis, then short-run isolation strategies, such as capital controls, could be highly effective in reducing the effect of a crisis elsewhere in the world. On the other hand, if crises are transmitted mainly through permanent channels that exist in all states of the world, then these short-run isolation strategies will only delay a country's adjustment to a shock. They will not prevent it from being affected by the crisis in the first place.

Although this paper has not identified exactly how shocks are transmitted internationally, it has suggested which groups of transmission mechanisms were and were not important during recent financial crises. As explained in Section 4, theoretical work explaining how shocks are propagated can be divided into two groups: crisis-contingent and non-crisis-contingent channels. Crisis-contingent channels imply that transmission mechanisms change during a crisis, and non-crisis-contingent channels imply that transmission mechanisms are stable during both crises and tranquil periods. Since the empirical evidence discussed in this paper finds that cross-market linkages do not change significantly during recent financial crises, this

evidence suggests that most shocks are transmitted through non-crisis-contingent channels, such as trade, country reevaluation and/or aggregate shocks. There is little support for crisis-contingent channels, such as those based on multiple equilibria, endogenous liquidity, or political economy.

This division between crisis-contingent and non-crisis-contingent channels is the critical distinction for evaluating the effectiveness of short-run isolation strategies. Recent crises appear to have been transmitted mainly through non-crisis-contingent channels, which are long-term linkages that exist in all states of the world. Short-run isolation strategies may be able to temporarily delay the transmission of a crisis from one country to another, but they cannot prevent the necessary fundamental adjustment through these long-term linkages. As a result, short-run isolation strategies, such as capital controls, will only have a limited effectiveness in reducing a country's vulnerability to shocks elsewhere in the world.[18]

Moreover, not only does this paper imply that the benefits of short-run isolation strategies are limited, but an extensive literature has also documented that these strategies could be extremely costly. Since crises are transmitted largely through long-run linkages such as trade, learning by market participants, and financial sector linkages, any policies aimed at reducing a country's vulnerability to a crisis would have to reduce these linkages. This would imply, for example, limiting trade flows with other countries or reducing the transparency of domestic institutions and regulatory processes (to reduce learning). Not only could implementing any of these policies be difficult, but it could be extremely costly. Would the cost of reduced gains from trade or less transparent institutions be worth any potential reduction in country vulnerability? Since most of the recent evidence suggests that the transmission of shocks depends on long-term fundamental linkages, there is no easy or obvious solution for building Latin America's immune system.

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[18] This result is consistent with Edwards (1998) which finds that capital controls had little effect in the transmission of the "Tequila effect".

Appendix: Tests of Shift-Contagion in a Generalized Framework

In this appendix, we examine the validity of some of the tests discussed above in a broader and more general framework.[19] We use a variant of the model discussed in the text. More specifically, assume that country returns during tranquil times are described by a factor model:

$$x_t = \alpha y_t + \eta_t$$
$$y_t = \beta x_t + \varepsilon_t$$

where the properties of the structural shocks are $E(\varepsilon_t) = E(\eta_t) = E(\varepsilon_t \eta_t) = 0$, $E(\varepsilon_t^2) = \sigma_\varepsilon^2$, and $E(\eta_t^2) = \sigma_\eta^2$. Also assume that there is a crisis in country x_t and that during the crisis the structural model becomes:

$$x_t = \alpha y_t + \eta_t + \lambda \eta_t$$
$$y_t = \beta x_t + \varepsilon_t + \phi \eta_t .$$

In this model, shift-contagion (as defined in the paper) is captured by the assumption that $\phi \neq 0$. This implies that the propagation of shocks during the crisis is different from that which exists during more tranquil periods. The crisis, or increase in the variance of country x_t is reflected in the assumption that $\lambda > 0$.

The relevant question is whether there exists a test that has power against the hypothesis $\phi = 0$ when $\lambda > 0$. It is well known, however, that in this model correlation estimates, principal components analysis, and OLS estimates are biased and inconsistent. Moreover, standard tests for stability (i.e. Chow tests) are inconsistent. Finally, the correlation adjustment discussed in the main text cannot be implemented because $\beta \neq 0$. Therefore, it is impossible to draw accurate inferences about parameter stability without making further assumptions.

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[19] This appendix was motivated by comments from Andrea Repetto in her discussion of this paper at LACEA. We thank her for providing us with this excellent interpretation of the test.

Most of the papers in the literature use exclusion restrictions in order to solve this problem. This paper has used the assumption that $\beta = 0$ to develop the correlation adjustment. This assumption is based on near-identification. More recently, other papers have experimented with a number of other assumptions.

This appendix explores an alternative identification procedure that does not require any additional exclusion restrictions to test for parameter stability. This is a new test developed by Rigobon (2000) for stationary variables (finite variance). The identifying assumption for the test is based on the form of the heteroscedasticity. In particular, if the heteroscedasticity in a sub-sample is explained by a shift in variances of only a sub-set of the structural shocks, then it is possible to test for structural change, even in the presence of endogeneity and omitted variables.

Financial crises are examples when the short-term variance in a set of emerging markets can be largely explained by the increase in the volatility of the country (or countries) experiencing the crisis. Rigobon's test has a simple form in the bivariate setting. If the parameters are stable and the heteroscedasticity is explained by a subset of the shocks, then the change in the covariance matrix is less than full rank. Formally, the two covariance matrices are:

$$\Omega_1 = \frac{1}{(1-\alpha\beta)^2}\begin{bmatrix} \beta^2\sigma_\eta + \sigma_\varepsilon & \beta\sigma_\eta + \alpha\sigma_\varepsilon \\ \beta\sigma_\eta + \alpha\sigma_\varepsilon & \sigma_\eta + \alpha^2\sigma_\varepsilon \end{bmatrix}$$

for the tranquil period, and

$$\Omega_2 = \frac{1}{(1-\alpha\beta)^2}\begin{bmatrix} (\beta + \beta\lambda + \phi)^2\sigma_\eta + \sigma_\varepsilon & (\beta + \beta\lambda + \phi)(1 + \lambda + \alpha\phi)\sigma_\eta + \alpha\sigma_\varepsilon \\ (\beta + \beta\lambda + \phi)(1 + \lambda + \alpha\phi)\sigma_\eta + \alpha\sigma_\varepsilon & (1 + \lambda + \alpha\phi)^2\sigma_\eta + \alpha^2\sigma_\varepsilon \end{bmatrix}$$

for the more volatile period. Notice that the change in the covariance matrices is:

$$\Omega_2 - \Omega_1 = \frac{\sigma_n}{(1-\alpha\beta)^2} \begin{bmatrix} \theta_2^2 + 2\beta\theta_2 & \theta_1\theta_2 + \theta_2 + \beta\theta_1 \\ \theta_1\theta_2 + \theta_2 + \beta\theta_1 & \theta_1^2 + 2(\theta_1) \end{bmatrix},$$

where θ_1 and θ_2 are given by

$$\begin{aligned} \theta_1 &\equiv \lambda + \alpha\phi \\ \theta_2 &\equiv \beta\lambda + \phi \end{aligned}.$$

Furthermore, the determinant of the change in the covariance matrix reduces to:

$$\det|\Omega_2 - \Omega_1| = -(\theta_2 - \beta\theta_1)^2 = -(1-\alpha\beta)^2 \phi^2$$

Therefore, under the assumption that the variables have finite variance ($|\alpha\beta| < 1$), the determinant is equal to zero if and only if $\phi = 0$. See Rigobon (2000) for further information and an application to tests for contagion.

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Table 1. Correlations in Stripped Yields on Brady Bonds for Select Emerging Markets

	Arg	Bra	Bul	Ecu	Mex	Mor	Nig	Pan	Per	Phi	Pol	Rus	Ven
Arg	1.00	0.99	0.96	0.98	0.99	0.99	0.99	0.98	0.99	0.96	0.97	0.87	0.97
Bra		1.00	0.93	0.98	0.97	0.99	0.99	0.98	0.99	0.97	0.95	0.92	0.99
Bul			1.00	0.95	0.96	0.95	0.94	0.92	0.94	0.87	0.89	0.81	0.92
Ecu				1.00	0.97	0.98	0.97	0.97	0.98	0.94	0.92	0.93	0.98
Mex					1.00	0.97	0.97	0.97	0.98	0.93	0.96	0.84	0.95
Mor						1.00	0.98	0.99	0.99	0.94	0.94	0.90	0.97
Nig							1.00	0.98	0.99	0.97	0.97	0.89	0.97
Pan								1.00	0.99	0.96	0.96	0.89	0.97
Per									1.00	0.96	0.96	0.91	0.98
Phi										1.00	0.97	0.89	0.96
Pol											1.00	0.80	0.93
Rus												1.00	0.95
Ven													1.00

Table 2. Correlations in Stock Market Returns for Select Emerging Markets

	Arg	Bra	Chl	Ecu	Egy	Hun	Mex	Mor	Per	Phi	Pol	Rus	Ven
Arg	1.00	0.78	-0.14	-0.31	0.48	0.78	0.71	0.38	0.41	-0.26	0.57	0.76	0.54
Bra		1.00	0.08	-0.12	0.80	0.88	0.27	0.53	0.62	-0.20	0.43	0.87	0.52
Chl			1.00	0.63	0.04	-0.28	-0.06	-0.59	0.73	0.70	-0.22	0.31	0.43
Ecu				1.00	-0.17	-0.42	-0.07	-0.60	0.43	0.45	-0.30	0.14	0.36
Egy					1.00	0.78	-0.08	0.66	0.43	-0.23	0.20	0.74	0.29
Hun						1.00	0.24	0.75	0.31	-0.47	0.51	0.70	0.34
Mex							1.00	-0.16	0.25	-0.02	0.45	0.56	0.48
Mor								1.00	-0.13	-0.73	0.14	0.13	-0.24
Per									1.00	0.32	0.12	0.75	0.69
Phi										1.00	0.07	0.02	0.25
Pol											1.00	0.50	0.38
Rus												1.00	0.90
Ven													1.00

Table 3. Coin Scenario 1

GAME 1 (penny)	GAME 2 (quarter)	FINAL PAYOFF (in cents)
Heads (+1)	Heads (+25)	+25.1
Heads (+1)	Tails (-25)	-24.9
Tails (-1)	Heads (+25)	+24.9
Tails (-1)	Tails (-25)	-25.1

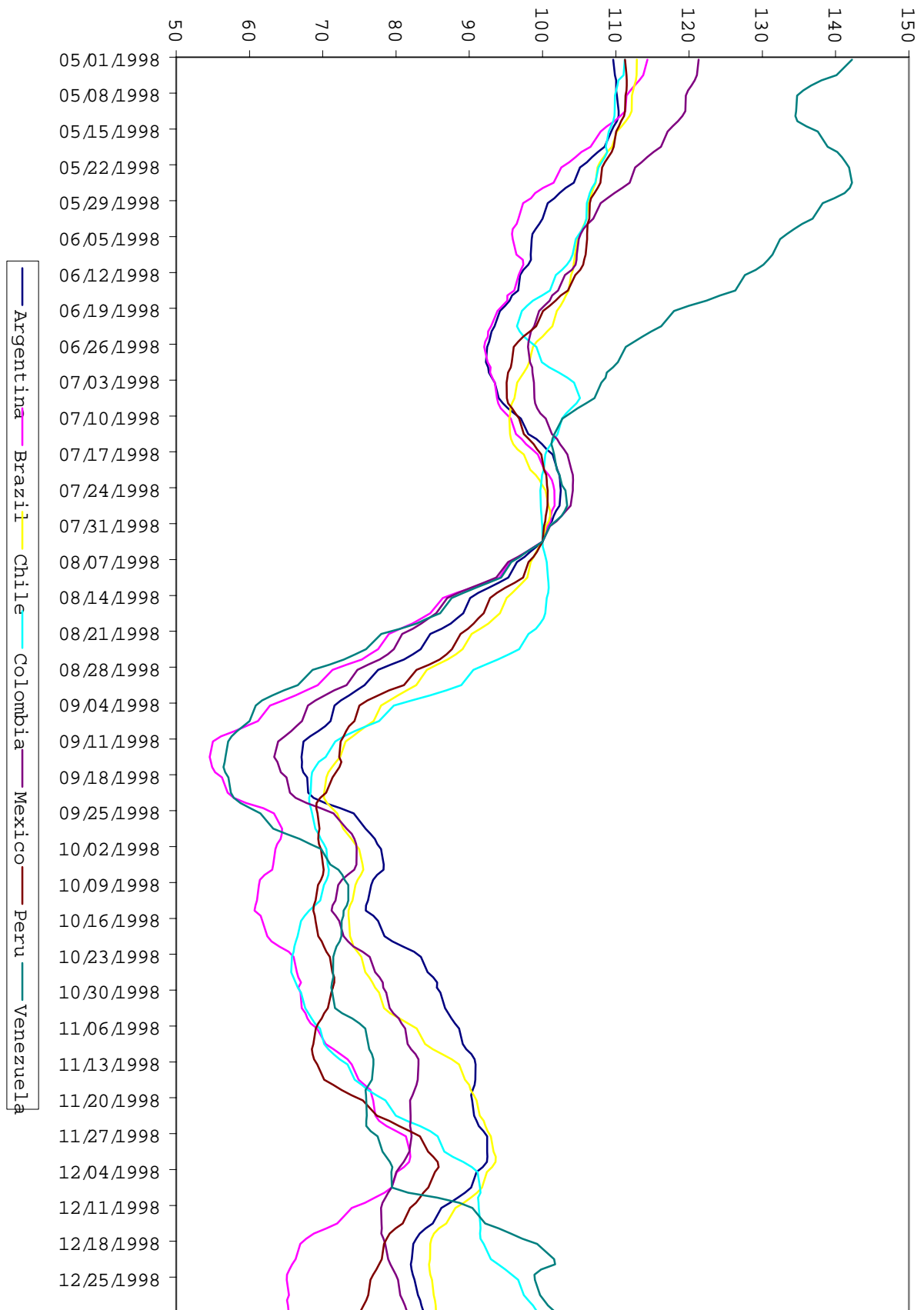*Note:* Final payoff is (10% x outcome of game 1) + outcome of game 2

Table 4. Coin Scenario 2

GAME 1 ($100 coin)	GAME 2 (quarter)	FINAL PAYOFF (in cents)
Heads (+10,000)	Heads (+25)	+1025
Heads (+10,000)	Tails (-25)	-975
Tails (-10,000)	Heads (+25)	+975
Tails (-10,000)	Tails (-25)	-1025

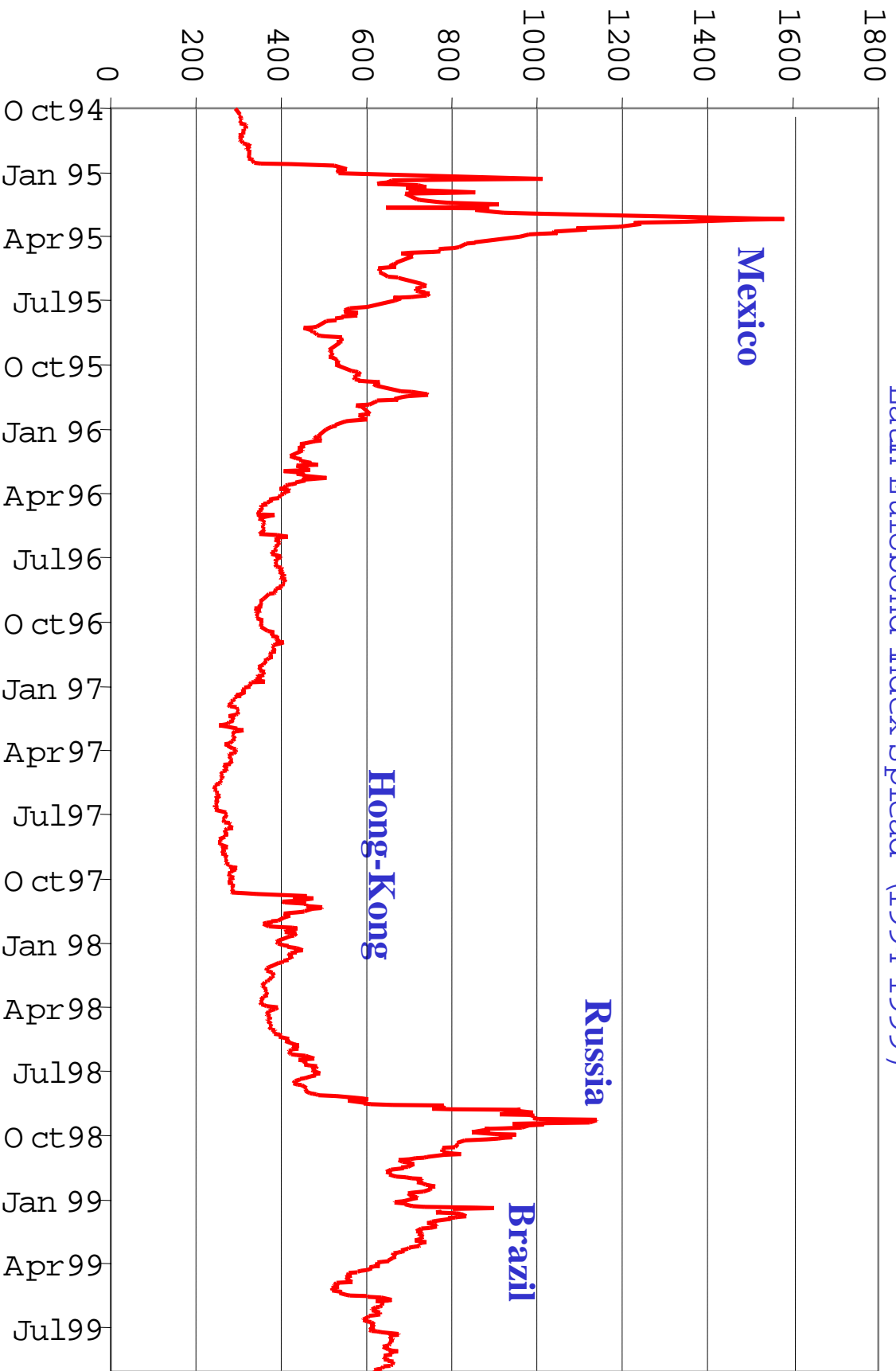*Note:* Final payoff is (10% x outcome of game 1) + outcome of game 2

Table 5. Coin Scenario 3

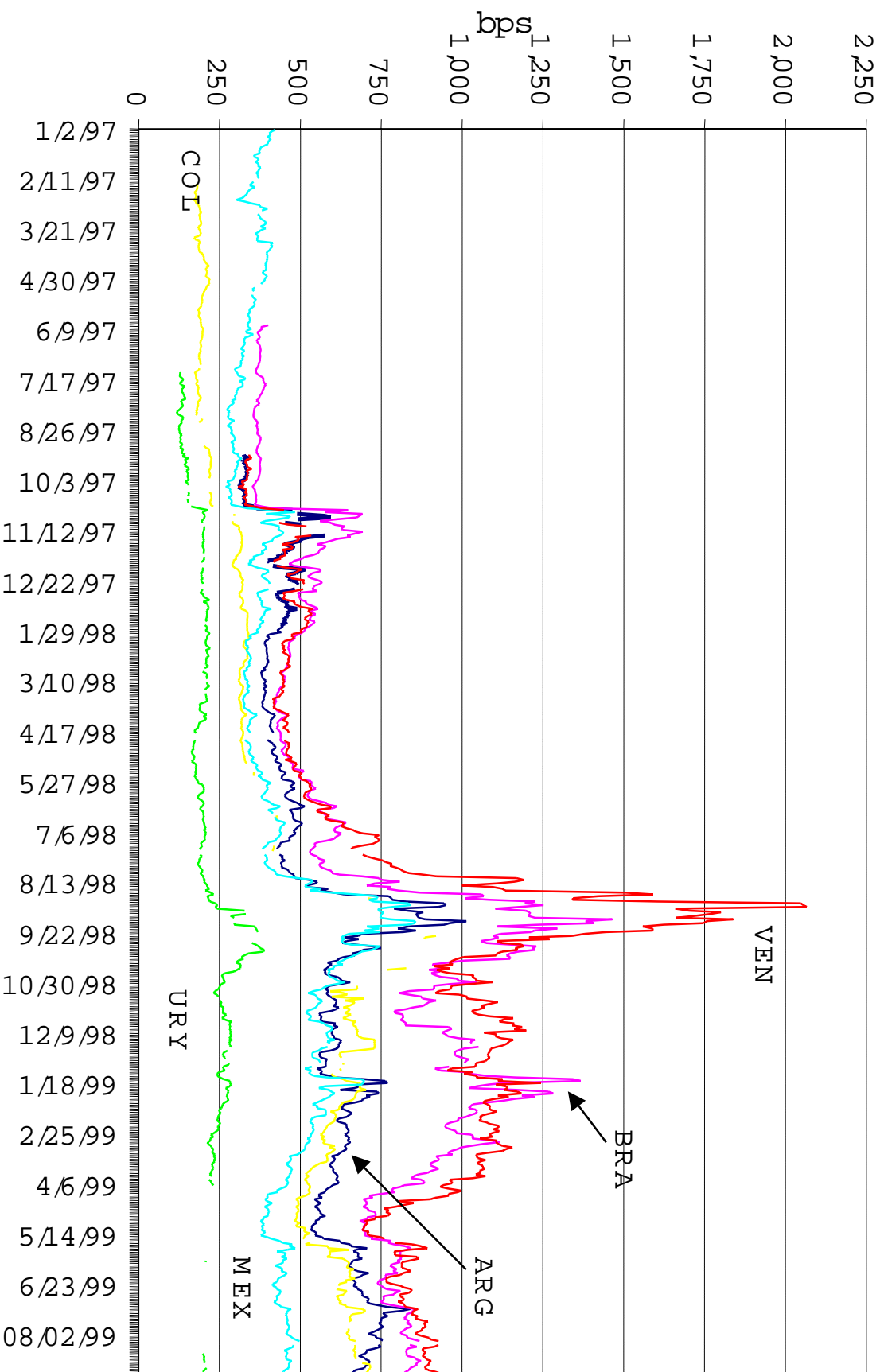| 2nd coin (quarter)		1st toss with a penny		1st toss with a $100 coin	
		Heads	Tails	Heads	Tails
	Heads	1	1	1	0
	Tails	0	0	1	0

Country Risk Volatility

Latin Eurobond Index Spread (1994-1999)

Stable Relative Valuations

Spread on Long-term Sovereign Bonds

bps

2,250
2,000
1,750
1,500
1,250
1,000
750
500
250
0

1/2/97
2/11/97
3/21/97
4/30/97
6/9/97
7/17/97
8/26/97
10/3/97
11/12/97
12/22/97
1/29/98
3/10/98
4/17/98
5/27/98
7/6/98
8/13/98
9/22/98
10/30/98
12/9/98
1/18/99
2/25/99
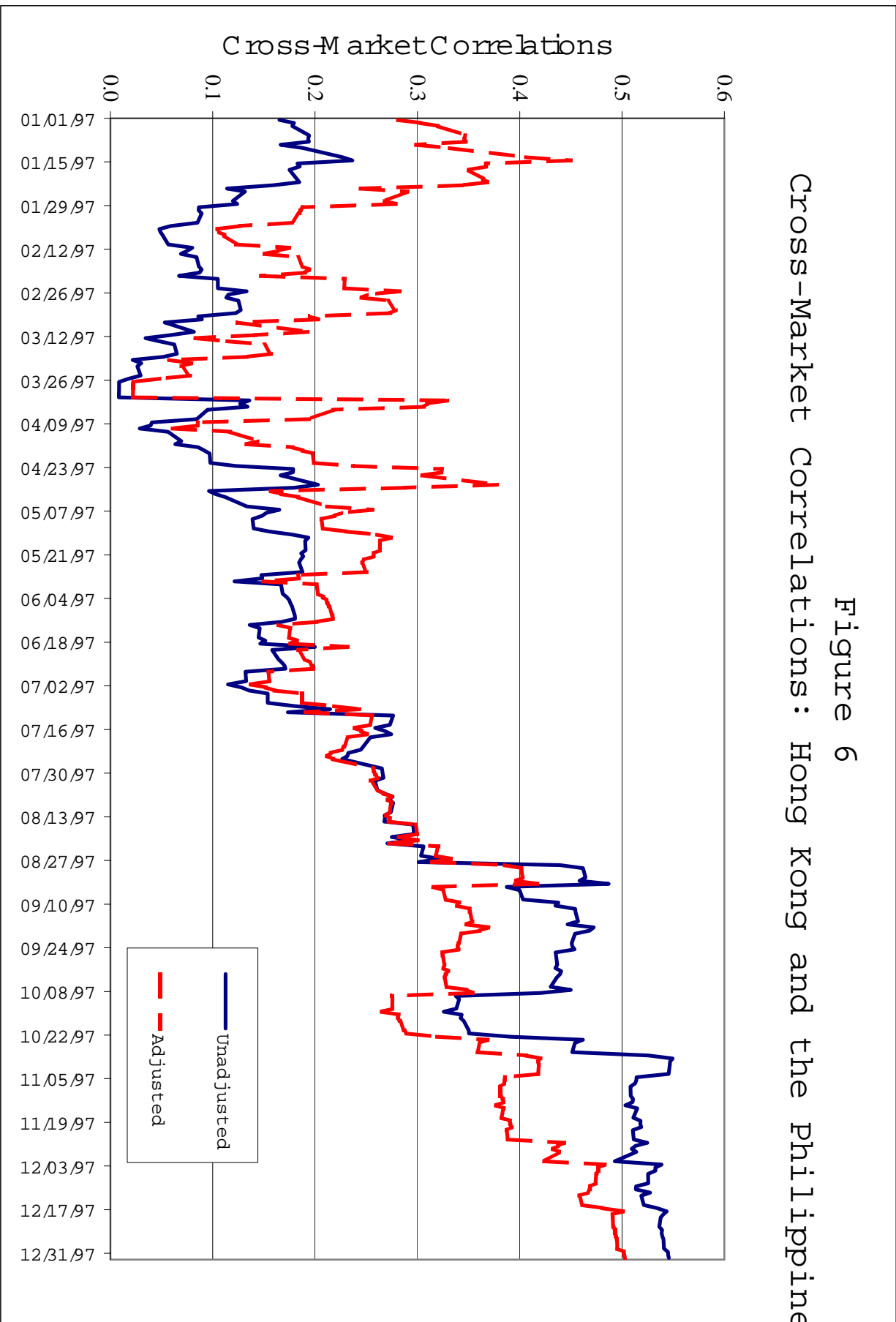4/6/99
5/14/99
6/23/99
08/02/99

COL

VEN

BRA

ARG

URY

MEX
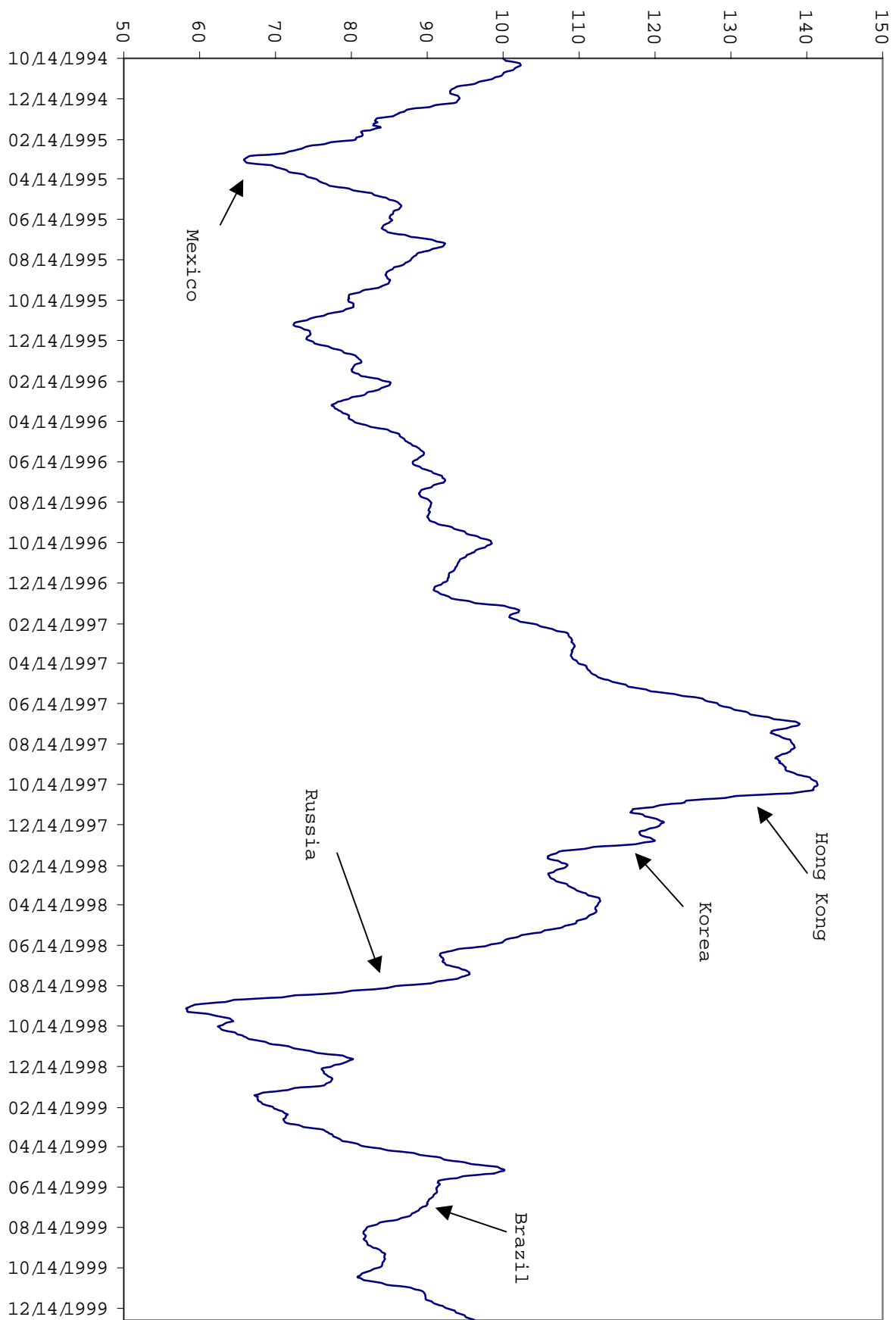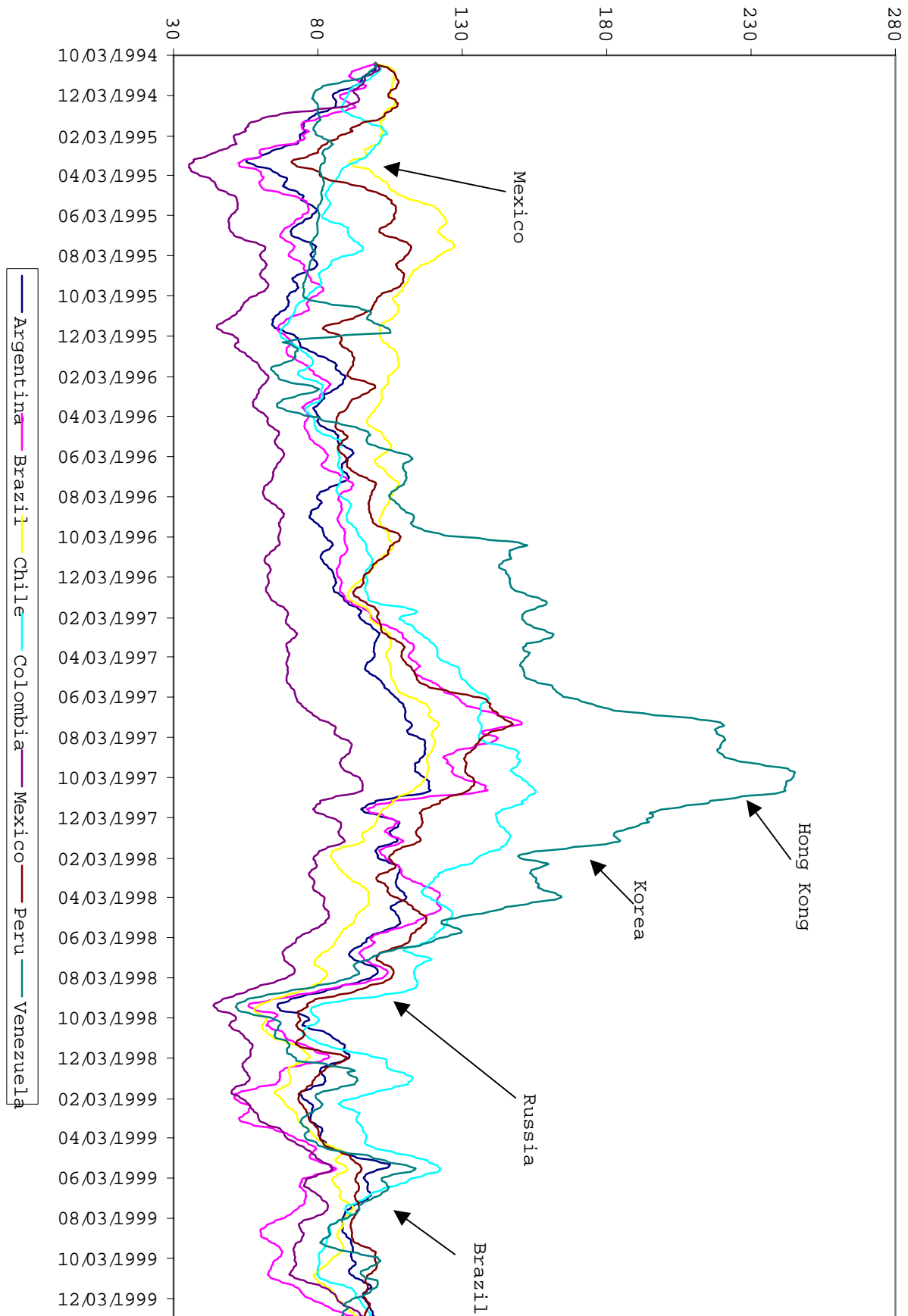
Figure 6
Cross-Market Correlations: Hong Kong and the Philippines