

Stochastic Network Susceptibility Models of the 1997 Asian Financial Crisis

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ABSTRACT

This project utilized stochastic network models to predict an economy's susceptibility to the financial contagion that was the Asian financial crisis of 1997. Economic interdependency was based solely on bilateral volumes of trade among eleven national economies that were affected by the crisis, and structural susceptibility was determined by the size of each economy. Two models, one based on imports and the other based on exports, were tested against observed economic trends. The analysis found no statistically significant difference in the correlations of the models against observed exchange rates of national currencies to the US dollar. Further, these high linear correlation coefficients in themselves suggest that stochastic models are practically robust in modeling financial crises. This corroborates the hypothesis that the percolation of the Asian financial crisis, at least in its early stage before IMF intervention on a large scale, was driven primarily through pure network interdependency as opposed to other extraneous factors.

It is widely accepted that the decision to float the Thai baht (THB) from its peg to the United States dollar (USD) in July 1997 was the catalyst to the Asian financial crisis. As a result, the baht became dramatically devalued immediately, and the crisis quickly spread to Thailand's trading partners in the fashion of a financial contagion. Currencies came under speculative attack as investor confidence plummeted; by October, devaluations vis-à-vis the USD averaged 20%-30% in Thailand, Indonesia, Malaysia, and the Philippines (Karunatileka 10).

Within this paper, it is important to note that the definition of financial contagion is a matter of some debate. Contagion is sometimes defined as "a significant increase in cross-market linkages after a shock to

one country." Others neglect cross-market linkages, instead arguing that contagion describes any situation in which a shock is transmitted from one country to another. The latter definition is the one that will be used in this paper. (Forbes and Rigobon 2002).

In this paper, we will attempt to use a stochastic model to track the likelihood of spread of the crisis. Classical susceptible-infected models use differential equations to approximate the expected proportion of a population affected by an infectious disease at a time. Such methods make the assumption that the probabilities that an interaction occurs and that the disease is transmitted are constant and invariant over an entire population. Though they often prove reliable in non-human networks, the fact that some interactions

are more likely than others, particularly in sociological structures, renders them unreliable in many man-made networks. This can be corrected by using a similar set of differential equations that takes into account the degrees of interaction between elements of the group using an adjacency matrix. Financial systems in particular are well-suited to network models.

This investigation had two main purposes. The first was to identify whether the gain of goods or the money used to buy them—that is, imports or exports—provides for a better model in predicting the extent to which each economy is affected by the crisis. The reason behind this dichotomy lies in supply and demand on a macroeconomic scale. Consider the uneven balance of trade between China and the US; China exports to the US much more than the US exports to China. If a financial crisis strikes China, it is harder to produce at internationally competitive prices, which raises the price of final goods in America. Businesses become less profitable, and the American economy suffers. Contrarily, if the US undergoes financial crisis, its national currency is devalued and all the US Dollars present in China lose their value. In this way, the Chinese economy is hurt as well. Thus, in essence, the big question asks whether the economic well-being of producers impacts the well-being of their consumers on an international level, and vice versa.

The second purpose was to determine if, in the early stage of the crisis, the contagion was percolated primarily by network interdependence or by other factors that are thought to have played substantial roles, such as weak fundamentals. As above, the word “interdependence” is based on values of imports and exports from country to country, while the word “contagion” is used colloquially as an infectious disease. The literature review below delves into greater detail

concerning the discrepancies in theories behind the percolation of contagion. The economies under consideration were those of Australia, China, Hong Kong, Indonesia, Japan, South Korea, Malaysia, Pakistan, the Philippines, Singapore, and Thailand. Note that remedial financial actions, such as the intervention by the International Monetary Fund (IMF) that is largely thought to be responsible for the aggravation of the crisis in its second stage, are discounted in this investigation.

This paper is structured as follows. Section II provides a brief review of the economic literature concerning the crisis. Section III covers the mathematical methods used to model financial interdependence among the key players. Section IV compares the results of the model against observed economic indicators, while Section V states the conclusions resulting from the analysis.

LITERATURE REVIEW

Economists such as Krugman (1998) claim that risky financial intermediary practices and prices of real assets were the primary forces behind the crisis. Indeed, Radelet and Sachs (1998), propose that a stochastic bubble is created whenever assets are purchased above their intrinsic market value. Over-inflated asset prices are known to have been the cause of the crisis (Karunatileka 10), implying that a correlation between the flow of assets and the probability that an economy approaches a “crisis state” exists. Glick and Rose (1998) used a bilateral export model as an indicator of interdependence to explain the regional scope of economic crises. An investigation of the Asian financial crisis by Woo et al. (2000) utilizes a logit model, also based on exports. Forbes and Rigobon (2002) incorporated interdependency in their model as well, though instead through cross-market comparisons.

The “stochastic bubble” as described

by Radelet-Sachs supports the use of the trade model that will be used in this paper. Such a model depends on a consistent and coherent definition of a transmission rate, as will be seen in the next section. Glick and Rose acknowledged that discounting for bilateral imports comprises a small imperfection in their model. This is the motivator for the first purpose of this paper: do imports or exports dictate economic interdependency—at least, insofar as determining the transmission rates of a financial contagion?

Woo used discrepancies between his model and observed data to show the unpredictability of crisis from trade data alone. This contradicts the findings of Forbes-Rigobon and to some extent those of Glick-Rose, which said that interdependency sufficiently explained the spread of the crisis. Woo instead proposes that financial panic¹, along with a host of other external factors, was ultimately responsible. This debate provides the motivation behind the second purpose of this paper: to what extent can trade interdependency explain the spread of the Asian financial crisis, in its early stage?

METHODOLOGY

By definition, the susceptible-infected (SI) model recognizes two states: susceptibility and infection. Though the apparent origin of the contagion was Thailand, it is important to note that the floating of the baht came amidst a system with near-ubiquitous fundamental flaws. However, for the sake of simplicity, it is assumed that the infected state came solely from Thailand.

We now turn to the network theory underlying the analysis. The adjacency matrix of an undirected graph or network is composed of ones to signify the existence of an edge between a pair of vertices,

and zeroes to signify the lack thereof. However, our investigation requires that the connectivity between two economies be weighted proportionally to the volume of trade between them. Further, the network must be directed, meaning that each edge has an inward or outward direction with respect to a vertex. The so-called “export model of interconnectivity” states that Economy A is dependent on Economy B to the extent that Economy A exports to Economy B.

In Figure 1, it can be seen that Economy A exports \$5 billion in goods to Economy B, and Economy B exports \$3 billion in goods to Economy A. Note the flow of trade as shown in the diagram refers purely to the goods being traded rather than the monetary transaction; otherwise, the arrows would be pointing in opposite directions. The idea behind this first model is that an economy is dependent on the money it receives from its transaction with another economy; if the currency value of the importer decreases, then the exporter suffers, and thus the contagion percolates. The adjacency matrix can then be constructed with the value of Economy A’s dependency on Economy B under A’s column and B’s row, while Economy B’s dependency on Economy A under B’s column and A’s row. We assign the first row and column to A and the second row and column to B. Note that a nation’s trade dependency on itself is always zero; the export model matrix looks like this:

$$\begin{array}{cc}
 & \begin{array}{c} A \quad B \end{array} \\
 \begin{array}{c} A \\ B \end{array} & \begin{bmatrix} 0 & 3 \\ 5 & 0 \end{bmatrix}
 \end{array}$$

Predictably, the “import model” says that the flow of foreign goods rather than currency indicates dependency on the exporter rather than the importer. The

¹ This factor was also cited by Radelet-Sachs (1998).

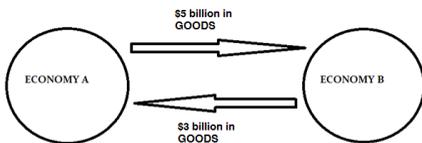
rationale here, as hinted in the introduction, is that businesses import due to comparative advantage: they realize that foreign firms can manufacture some goods at a lower opportunity cost than they can. When a nation's currency is devalued, comparative advantage is often lost, driving up the price of goods, to the detriment of the national economy. With the import model, the matrix is simply the transposition of the export model matrix, so it looks like this² :

$$\begin{matrix} & A & B \\ A & \begin{bmatrix} 0 & 5 \end{bmatrix} \\ B & \begin{bmatrix} 3 & 0 \end{bmatrix} \end{matrix}$$

From here we will adhere to the import model to avoid repetition. Suppose that Economy A carries the contagion. In this case, Economy B has less to worry about in the short run if it carries comparably large imports from the rest of the world. Thus the elements of the matrix must represent proportions of national imports. So if the gross imports of Economy A value \$100 billion and Economy B has \$200 billion, it would make sense to divide their respective columns by each of them, as shown:

$$0100520031000200=0.025.030$$

Figure 1



The transmission rate β of a network is defined as the probability that the infection spreads from one vertex to another. The β

2 Though intuition would suggest that the value of imports from A to B is equal to the value of exports from B to A, this often not the case according to the UN Trade Statistics Yearbook.

factor is typically multiplied to the adjacency matrix, but this is not necessary; by stating that increased trade makes an economy more likely to contract the contagion from its trading partner, this has already been worked into our adjacency matrix. However, a piece is still missing. Weaker economies are generally more susceptible to contagion than stronger economies are. As a simple workaround to this problem, each element of the matrix should be divided by the gross domestic product (GDP) of the economy in question. The β factor then becomes unique to each matrix element, as a trade proportion divided by GDP. If the GDPs of Economy A and Economy B are \$400 billion and \$500 billion, respectively, the final adjacency matrix of the import model is:

$$0400.025500.034000500=0.00004.0000750$$

It is easy to extrapolate both models to more than two countries. Figures 2 and 3 show the adjusted import and export model adjacency matrices for the eleven countries, respectively. Bilateral imports and exports were divided by each nation's total imports and exports as well as its GDP in that year as described above, and then multiplied by a factor of 1013 in order to make the numbers easier to read.³

From here, the model becomes a simple application of Euler's method of function approximation. By creating a system of equations $x_i(t)$, the probability that economy $1 \leq i \leq 11$ (where i corresponds alphabetically to each of the eleven economies in alphabetical order) lies in the infected state at time t ,⁴ we use Euler's

3 Obviously, this was done so that the numbers would not be negligibly small. Imports and exports were calculated with thousands of USD, while GDP was done with plain USD.

4 Another interpretation of $x_i(t)$ is the "proportion" of economy i that falls under the infected state at time t . This is the more concrete definition on which we will rely

Figure 2

Import	Australia	China	Hong Kong	Indonesia	Japan	Korea, Rej	Malaysia	Pakistan	Philippine	Singapore	Thailand
Australia	0.000	2.473	1.086	5.905	4.075	4.172	2.853	1.967	2.557	1.511	1.866
China	5.258	0.000	36.652	3.721	11.580	5.679	2.407	4.730	2.199	3.380	2.959
Hong Kong	1.157	5.061	0.000	0.611	0.737	0.760	2.335	0.382	4.205	3.198	1.054
Indonesia	2.183	1.642	0.810	0.000	4.351	2.669	1.828	1.147	2.040	0.000	0.950
Japan	13.027	21.019	13.405	19.810	0.000	20.919	24.688	10.228	21.838	18.153	30.548
Korea, Republ	2.965	8.933	5.388	5.617	4.567	0.000	5.221	2.670	5.147	3.436	3.495
Malaysia	2.175	1.616	2.185	1.919	3.368	2.000	0.000	5.294	2.471	15.016	4.569
Pakistan	0.185	0.247	0.408	0.440	0.165	0.188	0.063	0.000	0.152	0.000	0.091
Philippines	0.362	0.269	0.473	0.209	1.295	0.387	1.026	0.000	0.000	1.058	0.819
Singapore	3.407	2.594	5.253	6.698	2.097	1.681	13.438	1.624	5.263	0.000	5.879
Thailand	1.379	1.362	1.526	2.552	2.925	0.811	3.327	1.041	1.903	5.463	0.000

Figure 3

Export	Australia	China	Hong Kong	Indonesia	Japan	Korea, Rej	Malaysia	Pakistan	Philippine	Singapore	Thailand
Australia*	0.000	0.112	0.764	1.018	0.042	0.262	14.950	2.045	0.858	2.291	0.987
China	0.777	0.000	19.437	1.742	0.125	1.648	23.471	1.776	1.750	2.731	2.195
Hong Kong	0.887	2.212	0.000	1.376	0.145	1.612	56.646	13.073	4.633	8.965	3.430
Indonesia	0.674	0.096	0.315	0.000	0.052	0.463	14.975	2.078	0.760	0.115	1.131
Japan	3.795	2.076	3.711	10.912	0.000	2.284	129.914	9.052	19.588	8.251	11.005
Korea, Rej	2.032	0.504	0.934	2.779	0.167	0.000	29.604	4.081	1.978	3.056	1.189
Malaysia	0.580	0.092	0.534	0.940	0.088	0.628	0.000	0.583	3.666	18.120	2.366
Pakistan*	0.049	0.042	0.000	0.106	0.007	0.052	7.927	0.000	0.095	0.217	0.173
Philippine	0.319	0.068	0.674	0.583	0.048	0.276	11.528	0.761	0.000	1.848	0.741
Singapore	0.912	0.252	1.557	3.866	0.119	0.933	196.918	1.350	6.528	0.000	7.925
Thailand	0.458	0.084	0.568	0.697	0.104	0.383	39.384	1.444	4.162	5.712	0.000

method to iterate the equations with respect to a time interval Δt :

$$x_{it} + \Delta t = x_{it} + \Delta t dx_{it}$$

Let $A_{j,i}$ denote the element in the j th row and i th column of the adjacency matrix. Recall that $A_{j,i}$ by itself represents a probability that economy i is infected by economy j given that economy i is infected. When this is multiplied by x_i , this gives the probability that economy i is infected by economy j in any circumstance. When summed over all trading partners, we get the probability that economy i is infected by any of its trading partners. We then must multiply this by the probability that economy i is susceptible, $1-x_i$, to be sure that it already is not infected. This gives an expression for dx_{it} :

$$dx_{it} = 1 - x_{it} \sum_j A_{j,i} x_{jt}$$

Figure 4

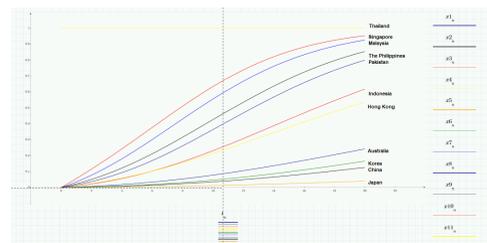
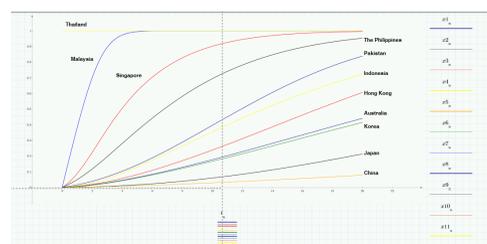


Figure 5



Substituting this expression in the general equation above gives:

in order to interpret our results.

$$xi_{t+\Delta t} = xi_t + \Delta t (1 - xi_t) A_j, i, x_j t$$

Note that the time unit for t is somewhat arbitrary, as there is no clear way to convert it to a familiar unit of time. Also note that xi can only increase but, as a probability, is bounded between 0 and 1. For this reason all of the functions will approach 1, often resembling a logistic curve (Teague 2012).

Figures 4 and 5 are the respective graphs of xi by the import and export models.

ANALYSIS

The program Mathcad was used to do all the computational work; the matrices were imported into the program and returned graphs (Figures 4 and 5) and values used in the statistical analysis later. The order of infection predicted by the import model as shown in Figure 4 is as follows: Thailand, Singapore, Malaysia, the Philippines, Pakistan, Indonesia, Hong Kong, Australia, Korea, China, and Japan. The order predicted by the export model deviates from the import model slightly, as shown in Figure 5: Thailand, Malaysia, Singapore, the Philippines, Pakistan, Indonesia, Hong Kong, Australia, Korea, Japan, and China.

Simple superposition of the models against actual economic indicators shows a surprising correlation. Figure 6 shows a particularly good case of the import model, Malaysia, while Figure 7 shows a good case of the export model, Japan. The model curve is shown along with the national stock market curve and monthly exchange rates to the USD⁵. Just as we would expect, exchange rates increase and stock indices plunge with the model. In general, exchange rates went back down

during the first few months of 1998⁶, so our models capture the appropriate time interval in these graphs. Model graphs for all economies are scaled the same way (0 < t < 20); stock market and exchange rates are taken from June to December 1997.

Figure 6

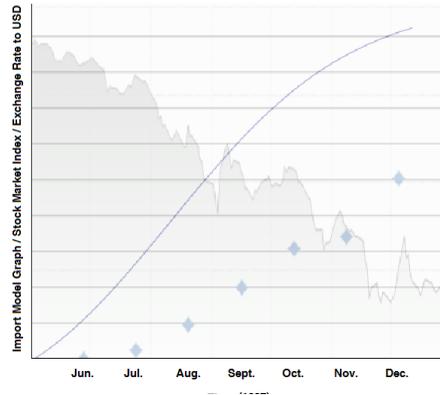
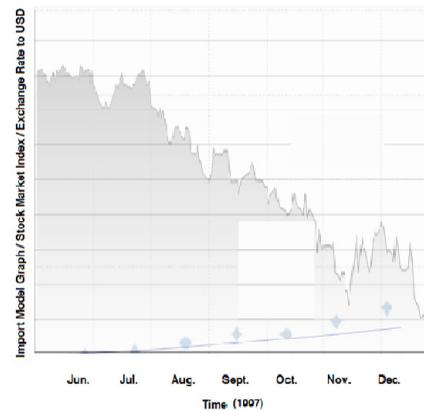


Figure 7



There is a more concrete way to compare the models with exchange rates. Consider the model for an economy over a certain period of time (i.e., that captured by the graphs in Figures 6 and 7). We have two data sets: the exchange rates to the USD for from June to July and the proportions predicted by the model, picked

5 To make a fair comparison across all exchange rates, each exchange rate was transformed into percent change from the June exchange rate.

6 Exchange rates subsequently went back up as the crisis entered its middle stage. However, this does not concern our model.

Figure 8

	Australia	China	Hong Kong	Japan	Korea, Rep.	Malaysia	Singapore
Import Model	0.957252	0.903624	0.45446	0.989203	0.83179	0.956133	0.902572
Export Model	0.936389	0.904188	0.452651	0.98536	0.770084	0.507908	0.800556

such that they lie between equally spaced time intervals. When we compare them, we should expect some correlation. A direct relationship would be ideal, so we easily find the linear correlation coefficients for each economy. Figure 8 provides a table of these coefficients for both the import and export models; Hong Kong stands as a notable exception in both cases, which will be discussed later.

A difference of means Student-*t* test can be performed to see if there is a statistically significant difference between the correlation coefficients between the import and export models for each individual economy. Following standard procedure for statistical inference, we let the null hypothesis H_0 represent no significant difference in the population means, while the alternate hypothesis H_a represents the contrary. When this is done, the test statistic is $t = .864645$, giving a two-tailed *p* value of $p = .420453$. Thus we fail to reject the null hypothesis, suggesting no significant difference in the means of correlation coefficients between the import and export models for any national economy tied to the Asian financial crisis.

CONCLUSION

The *t*-test reveals no statistically significant difference in the means between the import and export models of trade. This suggests that they are equally viable models of financial interdependency. While this result makes the importance of foreign currency versus foreign capital goods ambiguous, this in itself may raise deep questions about how we should model financial networks. Thus the first question

posed in the introduction is answered.

Overall high correlation coefficients attest to the efficacy of these models, but the case of Hong Kong stands out in its low correlation. This does not seem to make sense, since Hong Kong’s stock market falls while its exchange rate remains fairly level. However, both Hong Kong and China operate on a peg to the USD. Even when the Hong Kong dollar experienced speculative attack in August 1997, its value remained stubbornly resilient. The model developed here is not designed to account for any sort of government intervention; indeed, it probably would have reached very different results were it not for the Philippines’s and Malaysia’s abandonment of their own currency pegs in that year (Karunatileka 10).

This begs the question: how did both models achieve such high correlation coefficients with China? In 1996, China’s GDP, at nearly \$1 trillion USD, was the second highest in Asia. Though this was only about a fourth of the highest GDP in Asia (Japan), China’s import dependency on the so-called “MIT” economies—Malaysia, Indonesia, and Thailand—were a fraction of Japan’s⁷. In short, China’s aberrantly high coefficients are coincident with its monetary policy.

In addition, the general order of infection calculated by the model deviates minimally from historical observation. All countries under consideration were affected by the crisis within a very short time period of each other, yet even so the model is

7 China’s import dependency ratio on the MIT economies was 0.046, compared to Japan’s 0.106. Even more drastically, China’s export ratio was 0.0268 against Japan’s 0.104.

startlingly accurate in its predictions. Both models predict the closeness of Southeast Asian economies to the crisis, including the “MIT” economies (Krugman 1998). The relatively late impact on Korea’s economy, in addition to that of China, was also foreseen by the model.

For such a crude framework, the models perform well in predicting the patterns of the crisis. Given that they rely on trade interdependency, this

would imply that the crisis spread in a predictable fashion, disputing the opinion that weak fundamentals played a major role in its early stage. Thus the crisis can be explained by monetary and capital exchange, which can be explained by the formation of speculative bubbles, which can be explained by prices of real assets. This answers the second question brought about at the beginning concerning the percolation of the crisis.

ACKNOWLEDGEMENTS

Thanks to Dr. Dan Teague, for his superb teaching and helpful guidance. Thanks also to Mark Kirolos, Svend Larsen, and Ashwin Monian for their initial assistance in the project.

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FIGURE CAPTIONS

Fig. 1: Trade Between Economies A and B. Economy A trades goods to Economy B for \$5 billion, while Economy B trades goods to Economy A for \$3 billion.

Fig. 2: Import Method Adjacency Matrix. Each element represents imports from the country in its column to the country in its row in the year 1996, divided by 1996 national GDP and total imports, and multiplied by a factor of 1013.

Fig. 3: Export Method Adjacency Matrix. Each element represents exports from the country in its row to the country in its column in the year 1996, divided by 1996 national GDP and total imports, and multiplied by a factor of 1013. (Sources: United Nations 1996 International Trade Statistics Yearbook, United Nations Commodity Trade Statistics Database)

Fig. 4: Import Model Graph—Proportion of Economy Infected vs. Time, t . The equations x_i represent the economies in alphabetical order: Australia, China, Hong Kong, Indonesia, Japan, Republic of Korea, Malaysia, Pakistan, the Philippines, Singapore, and Thailand. Graphs were generated by iterating Euler's method as described in Section 3.

Fig. 5: Export Model Graph—Proportion of Economy Infected vs. Time, t .

Fig. 6: Malaysian Import Model Graph. The solid curve represents the graph predicted by the import model, the shaded graph is the Malaysian national stock index, and the plotted points are exchange rates to the USD. The key here and in Figure 7 is not necessarily that exchange rates and the import model the same, but that they track together to a uniform scale set up for all graphs, making a vertical scale virtually meaningless.

Fig. 7: Japanese Export Model Graph. The solid curve represents the graph predicted by the import model, the shaded graph is the Japanese national stock index, and the plotted points are exchange rates to the USD. (Sources: X-Rates, Trading Economics)

Fig. 8: Correlation Coefficients of Import and Export Model