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International Input-Output Linkages and Exogenous Shock Transmission: A Simple Model and Evidence from the Global Financial Crisis

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Abstract: This paper develops a simple model of shock transmission through the global input-output network. It finds that the impact of a negative shock on distant nodes is related to the eigenvector centrality score of those nodes. This finding is independent of behavioral assumptions, and flows only from the structure of the network. The prediction is tested using data on output changes due to the Global Financial Crisis of 2008-2009. Econometric models lend strong support to the model: centrality has a significant, negative impact on output changes following the crisis. Network structure, covering interlinkages among all sectors of the economy, not just finance, therefore seems to be an important part of the crisis propagation story.

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Keywords: Networks; Centrality; Global Financial Crisis; Input-Output.

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1 INTRODUCTION

Recent theoretical work has shown that a standard input-output matrix can be understood as a directed graph in terms of the applied mathematics literature (e.g., Acemoglu et al., 2012). Applying some basic assumptions on economic behavior makes it possible to mobilize concepts from network science to understand the properties of various types of input-output relations, including the origins of aggregate fluctuations in micro-shocks, and the stability properties of different network configurations.

This paper builds on the existing literature in three ways. First, it uses an inter-country input-output framework, rather than the single country frameworks that have previously been studied. Second, it proposes a simple model of shock transmission that does not require any assumptions as to economic behavior, but relies solely on the properties of the network. The model is well suited to understanding transmission of an idiosyncratic shock, such as one large country-sector specific shock; this framework contrasts with Acemoglu et al. (2012), who aggregate micro-shocks from throughout the input-output network. Third, it takes the model to the data, and shows that network properties played a significant role in international transmission of the Global Financial Crisis.

The paper proceeds as follows. Section 2 develops the model from basic network properties. Section 3 takes it to the data. The final section concludes, and discusses directions for further research.

2 SHOCK TRANSMISSION IN AN INTERNATIONAL INPUT-OUTPUT NETWORK

Following Acemoglu et al. (2012), let A be an input-output matrix. We partition the matrix so that multiple countries and sectors are included, i.e. it is an inter-country input-output matrix:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1j} \\ & \ddots & \vdots \\ a_{i1} & \dots & a_{jj} \end{bmatrix}$$

Each entry a_{kl} captures inputs from country-sector l used in the production of output in country-sector k. Entries are expressed as technical coefficients, i.e. they are divided by column sums (total output). All entries of A are between zero and one, so it is a stochastic matrix.

Consider a vector of exogenous shocks, C. Transmission of the shock can be likened to the progress of a random walk: starting at any point a_{kl} in the matrix, it moves to that node's neighbors according to the transition probabilities given by A. In other words:

$$C_{t+1} = AC_t$$

We postulate that the random walk converges as t approaches infinity. If that is true, then it must be the case that there is a steady state such that:

$$C^* = AC^*$$

It can therefore be seen that the steady state probability matrix representing the result of an infinite-length random walk corresponds to the right eigenvector of A with unit eigenvalue. By the Perron-Frobenius Theorem, given that A is a stochastic matrix, C* exists with a corresponding eigenvalue equal to one, and contains all entries between zero and one. In the applied mathematics literature, it is known as eigenvector centrality. It has two complementary interpretations: it is both the importance of a country-sector in the network expressed as a weighted sum of the importances of all other country-sectors to which it is connected, and the probability that a shock occurring at any point in the network and transmitted through input-output linkages arrives that that node. Importantly, it represents a long-term impact of the shock, in the sense that all adjustments have taken place.

Many concepts of centrality exist in the applied mathematics literature. Acemoglu et al. (2012) show that a similar one, Katz-Bonacich Centrality, is related to shock transmission in their model, which considers aggregation of micro-shocks across many sectors. The above model assumes that there are no disconnected nodes in the network, but a simple solution for that problem exists in the form of Google's PageRank algorithm, which is a modification of eigenvector centrality (Bryan and Liese, 2006).

3 Empirical Evidence

The starting point for our analysis is the inter-country input-output table produced by the World Input-Output Database. Tables are available for years 2000 to 2014, and cover 43 countries (including an aggregate rest of the world region) and 56 sectors. Construction of the database is discussed by Dietzenbacher et al. (2013), and Timmer et al. (2015). We calculate centrality using 2005 data; it is well prior to the shock we are examining, and so is plausibly exogenous to it. To simplify the analysis, we eliminate all sectors with zero recorded output, and correspondingly zero use of inputs (disconnected nodes). This leaves us with 2,296 country-sector pairs.

To transform the basic input-output matrix into stochastic form, we divide by column sums (total output). We then extract eigenvector centrality scores. Figure 1 shows the distribution of centrality scores. It is consistent with the existence of a few very central nodes, and a large number of relatively isolated ones. Interestingly, the US financial sector is the fifth most central node in the network, with a score of 0.24.

In reality, all nodes in the input-output network are constantly experiencing shocks, typically quite minor ones with only limited implications for the rest of the network. A strong test of the hypothesis developed in the previous section is a relatively localized shock, which propagates in a way not dissimilar from a random walk. Regardless of the location of the source node of the shock, our contention is that subsequent changes in output should be associated with eigenvector centrality.

A good candidate is the financial shock that hit US markets in 2008-2009. From its US beginnings, the shock rapidly spread overseas, leading to an historic decline in trade, and resulting lost output and unemployment. In terms of size, it dwarfs other shocks in the inter-country input-output network around the same time. We therefore calculate the difference in output from 2007 (the pre-crisis peak) to 2009 (the crisis-induced trough), drawing again on the World Input-Output Database.

Figure 2 shows that there is a negative association between the change in output from 2007 to 2009, and eigenvector centrality: in other words, more central country-sector nodes tended to see a greater decrease in output due to the crisis. This preliminary finding sits well with our simple model.

To test this insight more rigorously, we estimate two econometric models, one for the raw change in output (first differences), and one for the proportional change in output (log first differences). Both models include full sets of country and sector fixed effects to account for other possible influences on the change in output. Results are in Table 1. Although the simple model in Section 2 was in terms of absolute changes, the econometric results suggest that eigenvector centrality is an important predictor of both absolute and proportional changes. The coefficient on the variable of interest is negative, as expected, and statistically significant at the 1% level in both equations. It has significant explanatory power. For example, the automobile sector in Germany suffered an output loss of $98bn between 2007 and 2009, and the first estimating equation suggests that \$7.5bn (7.7%) of that was due to the network effects captured by our simple model. Further from the locus of the shock is the construction sector in Korea, which saw output contract by around \$30bn over the same period, of which about \$0.4bn (1.3%) is attributable to the network effects captured by eigenvector centrality. Clearly, impacts differ across countries and sectors, but the regression results and their quantitative interpretation make clear that international input-output relationships played a significant role in transmitting the crisis beyond the US financial sector.

Although we have taken centrality scores from 2005 to limit endogeneity concerns, we need to go further to ensure that the shock we are considering is genuinely exogenous to the network. Results in the first two columns include all sectors and countries, i.e., including the USA and the financial sector, which was the source of the shock. It is possible that our results are being driven in part by this inclusion, and by the special linkages that exist among financial sectors around the world, and which were particularly stressed by the US crisis. To address this possibility, we present three additional sets of regression results: one dropping the USA, another dropping the financial sector, and a third dropping both the USA and the financial sector. The increasingly strict sample selection helps support an argument that the shock we are considering is genuinely exogenous to the reduced network, which does not include the locus of the shock, or its neighboring nodes.

Results using the restricted samples are in Table 2. In each case, eigenvector centrality has a negative and statistically significant (5% or 1%) coefficient. Based on these results, it is highly unlikely that our findings are an artefact of endogeneity of the shock we are considering, but instead represent a genuine connection between the structure of the network, and the way in which exogenous shocks are propagated.

4 Conclusion

This paper has produced a simple model of shock transmission through an inter-country input-output network. This simple model, which does not require any assumptions as to economic behavior but flows only from the structure of the network, makes it possible to derive a simple index of centrality that is negatively correlated with output changes following the shock. More central nodes have greater output losses. We have verified the model's predictive power using data for the Global Financial Crisis—the centrality index has economic, as well as statistical, significance. Our findings suggest that the structure of global input-output relationships, covering all sectors, not just finance, contributed to the spread of the crisis in 2008 and 2009.

There are many avenues for further research in this direction. As Acemoglu et al. (2012) show, there is scope for developing alternative models of shock transmission based on network characteristics. Issues like cascading and stability are clearly important, but need a more complex framework in order to be understood. There is also scope for more empirical work to highlight the importance of these mechanisms in practice.

References

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TABLES

Table 1: Baseline regression results.

	D. Output	D.Ln(Output)
	All	All
Eigenvector Centrality	-173064.853***	-0.339***
	(0.002)	(0.001)
Constant	9344.460***	0.017*
	(0.010)	(0.092)
Observations	2296	2296
R2	0.353	0.366
Country fixed effects	Yes	Yes
Sector fixed effects	Yes	Yes

Dependent variable appears at the top of each column. Estimation is by OLS. Prob. values based on robust standard errors clustered by country are in parentheses beneath the parameter estimates. Statistical significant is indicated as follows: 10% (*), 5% (**), and 1% (***).

Table 2: Robustness checks.

	D. Output	D.Ln(Output)	D. Output	D.Ln(Output)	D. Output	D.Ln(Output)
	No USA	No USA	No Finance	No Finance	No USA, No Finance	No USA, No Finance
Eigenvector Centrality	-149316.720**	-0.378***	-179025.244***	-0.327***	-154968.373**	-0.360***
	(0.047)	(0.001)	(0.002)	(0.001)	(0.042)	(0.001)
Constant	8917.128**	0.016	9359.545***	0.017	8932.806**	0.015
	(0.017)	(0.128)	(0.010)	(0.103)	(0.017)	(0.143)
Observations	2241	2241	2252	2252	2198	2198
R2	0.389	0.361	0.346	0.364	0.381	0.360
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Dependent variable appears at the top of each column. Estimation is by OLS. Prob. values based on robust standard errors clustered by country are in parentheses beneath the parameter estimates. Statistical significant is indicated as follows: 10% (*), 5% (**), and 1% (***).

FIGURES

Figure 1: Distribution of eigenvector centrality scores, 2005.

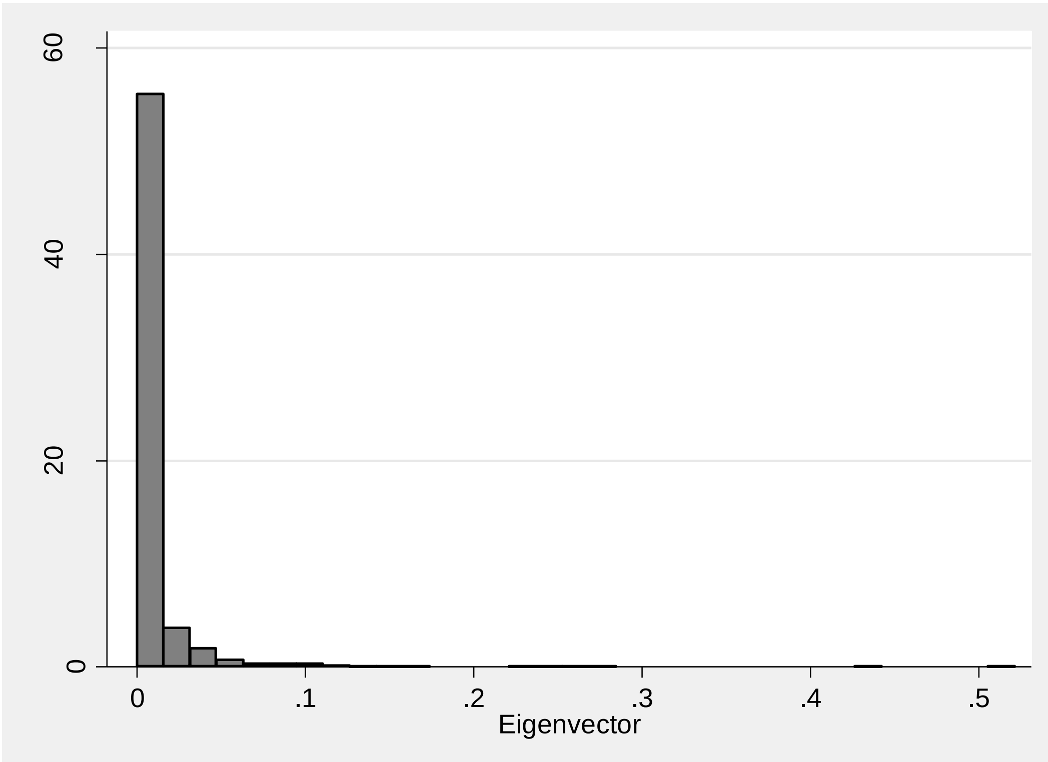

Figure 2: Association between eigenvector centrality (2005), and change in output (2007-2009).