Flow Centralities: Do they Predict the Economic Rise and Fall of States?

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The problem of measuring the centrality of states, and of explaining the economic rise and fall of states, is a central issue engaging social theorists accounting for social structure and change. Indeed, the problem arises not only in recent times, but rather has always been a current one. Theorists tend to agree that long term macroscopic perspective is needed to situate the problem in a formal way. In this field, however, the problem has not been situated previously on the appropriate structural measurements. This paper develops a structural model of the economic rise and fall of states based on formal measures of flow centrality. Its wider concern is with the dynamics and consequences of differential position and centrality in exchange networks.

Positions in world economies change, often slowly, sometimes abruptly, but there have tended to be some notable constants. Civilizations typically always have core states and peripheries. These are defined by their relative positions and/or centralities in the world economic system. Civilizations usually also have semiperipheries that stand in between the core areas and peripheries in a transaction network. In the history of civilizations, typically core cities and states rise and fall, semiperipheries move up to core status, and peripheries into the semiperiphery; as older cores and semiperipheries eventually move down.

Several major competing theories about mobility and centrality are tested here using data on multicommodity trade flows in the contemporary world economy between 1965 and 1980. One is the Adam Smith/Allyn Young model of the

vertical division of labor, where success in the market and of the market depends on the ability to insert new processes into transaction chains in which products are successively transformed (Kaldor 1985: 63-65). As Young (1928) emphasized "The important thing of course is that with the division of labor a group of complex processes is transformed into a succession of simple processes, some of which, at least, lend themselves to the use of machinery." This would suggest that core countries came to be core not because of GNP, production, or exports, but because of the vertical integration of commodity flows as throughputs to the state economy. This view, and its larger field of theory as developed by Kaldor (1985), would suggest that the measure of centrality most relevant to mobility would be the brokerage or betweenness of flows for critical commodities, as well as the structure of multi-commodity flow systems.

A second model derives from dependency theory, credited to Johan Galtung (1971) and Andre Gundar Frank (1969, 1978, and 1979) and developed by political economists, arguing that peripherality is a self-amplifying hierarchical system of dependency chains on successive metropolitan regions of increasing scale. The concept of dependency is different than but related to betweenness or brokerage in that brokerage implies the dependencies of others, and dependency implies the brokerage of others. In a system of transactions, these are relational or network concepts.

A third model derives from theories about the importance of changes in the horizontal component of the international division of labor, in which specializations in different kinds of commodities are advantageous depending on how wages and capital relate to positions in the world economy. For example, low wage/light manufacturing allows semiperipheries to dominate exports to leverage their mobility in the world system. Recently we have witnessed the rise of the four "Asian Tiger" economies of Taiwan, South Korea, Singapore,

and Hong Kong. Jane Schneider (1977, 1987) argues that the export of textiles and clothing have been historically key to mobility into core status or shifts in core hegemony.

The testing of competing theories against empirical data, with appropriate measurements, is an important step in integrating scientific discourse on this long studied and highly controversial topic. New measures of centrality allow for a more precise formulation and testing of older theories.

POSITION AND CENTRALITY

The concepts of position and centrality from network theory can help to understand these theories of mobility, and to formulate predictions about changes in position in the world economic system as a possible effect of the relative centrality or peripherality of a unit's linkages within that system. By clearly separating the concepts of structural position, on the one hand, the relative standing of competing units on the other, regardless of their position, we can understand how the latter may provide the leverage for movement or change in position.

The first concept is that of role or relative position. Position is defined by the pattern of ties in a network of relations -- where a unit stands with respect to classes or types of others, and relative to how these linked others are themselves linked, in turn, to still others at a further distance. The concept of relational equivalence (White and Reitz 1983) has been operationalized as an algorithm for measuring the relative similarities or differences among units that are networked by one or more types of links. It provides a basis for measuring positional distances among nations in the world economy, and for deriving clusters of units with nearly identical positions -- such as core, semiperiphery, periphery -- in such a transactional network. In Smith and White (1988) we apply a suitable variant of this algorithm to international trade data in 1965, then again in 1970 and 1980.

From the structural classification of countries by position at these three time periods blocks of countries are identified. Since there are the same number and type of blocks from period to period -- i.e., a common positional structure over time (one core block, strong and Weak semiperip1eries, and strong and weak peripheral blocks) -- the result is to show the relative mobility of countries across these blocks over time. This account of position in the world economy is the dependent variable that we now wish to predict by the second of our structural measures.

The second concept is that of centrality. As defined by Freeman (1979) for connected undirected grcqi1s, there are three aspects of the centrality of individual nodes: 1) the number of links, or degree of each point; 2) the capacity of a unit to transact with others independently of paths that involve intermediaries, or closeness of each point to the conceptual center of the graph_ and 3) the extent to which a unit serves as an intermediary path for Direct transactions between other nodes that cannot reach one another directly, or betweenness of each point. The measures of betweenness and closeness require the calculation of shortest paths (geodesics) between each pair of points to compute the relative extent of direct and indirect linkage. Freeman (1980) also provided a measure of pairwise dependencies, and has shown that betweenness is a function of the sum of dependencies on a point, while distance from the center of the graph (the inverse of closeness) is a function of the sum of one's own dependencies.

To apply these concepts to international trade, we need first to generalize Freeman's measures (1979, 1980) of centrality to directed graphs with real-valued flows. In flow graphs, the analog of geodesics is defined by maximal flows (maxflow) between each pair of points, given all the direct and indirect links (Ford and Fulkerson 1962); direct and indirect linkage can thus be computed. The pairwise dependence of each point on a specific other

(e.g., for exports) is computed by taking the proportion of this point's maxflow exports to all other points that go (indirect1.y) through the specific other. The sum of others' dependencies on a point is a measure of this point's relative betweenness. The sum of its dependencies on others measures its flow-distance to the conceptual center of the graP1 (the inverse of its relative closeness). In the present context, we call this the measure of dependency or point dependence. We call the third measure of centrality each point's **maxflow**, for its total maxflow (e.g., of exports) or degree. Since imports and exports are not equivalent, each of the three measures may be defined separately for imports and exports.

We will illustrate this family of concepts and measures for flow centrality, and then came back to the theoretical issue of how and which centralities are dynamically implicated in jockeying for position in the world economy.

AN ILLUSTRATION: CENTRALITY MEASUREMENTS FOR A HIERARCHICAL FLOW GRAPH

For high-tech heavy manufactures the pattern of commodity trade between blocks in the world economy typically shows highest flows from the top blocks, with larger flows downward between adjacent blocks, and diminishing flows downward between blocks that are more distant in the hierarchy. A simple 5-point graph in Figure 1 (ignoring differences in core/periphery volume) will serve to illustrate the computation of flow centrality measures. Here, flows between points 1, 2, 3, 4, 5 are all downward (e.g., exports from 1 to 2, 2 to 3, 1 to 3, etc.), flow is greatest between adjacent pairs, and is least between distant pairs. Table 1 shows the graph in matrix form, and the computation of maximal flows. The numbers in the lower diagonal indicate exports are from columns 1-4 to rows 2-5. The upper diagonal is all zeros, indicating that the flows are one directional.

(Insert Figure 1 and Table 1 about here)

The measures in Table 1 show that import betweenness centrality is greatest for points 3 and 2, export betweenness greatest for points 3 and 4. Dependence on import brokers increases from 1-2 to 3, 4, and 5. Dependence on export brokers increases from 5-4 to 3, 1, and 1. The import maxflow increases from 1 to 5 and the export maxflow increases from 5 to 1.

BEIWEENNESS FLOW CENTRALITY AND COOK AND EMERSON'S EXCEANGE THEORY

Cook, Emerson and Gillmore (1983) argue that power accrues in exchange networks (with flows of transactions) not to those persons most central in terms of Freeman's (1979) geodesic closeness to the center of a graph nor his geodesic betweenness centrality, but to those persons who mediate the "poles" of the system. They give the example of the experimental exchange network in Figure 2, where more solid lines represent more profitable exchange opportunities than dotted ones (by a factor of three to one). In this situation, power accrues to position E (a flow intermediary) over D (the "Freeman" center) and F (the periphery).

Table 2 shows this structure as a flow matrix, but as if the transactions did not actually flow. (If maximal throughputs were computed every pair would have the same maximal flow of 4 units.) The betweenness centrality computations show the desired result: position E shows the highest betweenness. (The reason why this hypothetical example gets any results at all is that each point is assumed to mediate its own direct links, and there are, here, only direct links. Connections between our measures and Cook's concepts require further exploration. Variants of our algorithm might be considered with respect to such auto-mediation, and/or attenuation of flows in indirect paths, etc.)

BEIWEENNFSS FLOW CENTRALITY: IMPORTS AND EXPORTS

The usefulness of separate centrality measures for imports and exports can be seen by two situations (Figures 3 and 4) that exemplify contrasting types of high centrality. In Figure 5 country 2 is high in import

centrality: countries 5, 4, and 3 depend on 2 for their imports from 1. In Figure 6 country 4 is high in export centrality: countries 1, 2, and 3 depend on 4 for their exports to 5.

Betweenness allows the strategic use of market position to improve profits on flows through an exchange system. In a market situation, with high import betweenness, a player can buy at bulk “wholesale” rates from one or a few suppliers, and sell at retail prices to many buyers. Disregarding monopolies by the supplier, this is the position that is good for the "buy cheap sell dear" strategy of mercantile economic advancement, or in the Adam Smith/Allyn Young model, of inserting oneself into the vertical division of labor by virtual of a specialized manufacturing process that is part of a longer chain of product transformations.

High export betweenness, conversely, is detrimenta1 to a player's economic health -- with small flows from many suppliers and large flows a one or a few buyers, the player in this position is under pressure to buy dear and sell cheap -- with clear implications for profit margins.

Thus, barring trade monopolies, (hypothesis 1) import betweenness (of certain commodities) should predict upward mobility in position in the world economy. Conversely, for certain commodities, (hypothesis 2) avoidance of export betweenness is predicted relative to import betweenness. However, the two may be confounded because of problems such as scale, i.e., the greater level of exports required for import betweenness is often correlated with higher imports.

CLOSENESS FLOW CENTRALITY: IMPORTS AND EXPORTS

The utility of separate centrality measures for imports and exports is again seen by a contrast of situations (Figures 5 and 6) that imply high centrality for each. In Figure 5 countries 1 and 2 are independent of import brokers, with 3, 4, and 5 increasingly dependent on import brokers. In Figure 4 countries 5 and 4 are dependent of export brokers, with 3, 2, and 1 increasin1ly dependent on export brokers.

High import broker independence is an obvious economic benefit, looked at the other way around, under normal market conditions, where dependence on import brokers is high (e.g., country 1 in Figure 5), countries can be expected to pay premium rates for imports. Thus, (hypothesis 3) import independence centrality (of certain commodities) should predict mobility in position in the world economy.

In contrast, high export broker independence is an economic detriment, since export brokers help to market exports. This is a kind of centrality to be avoided. Thus, (hypothesis 4) for certain commodities, all positions in the world economy are predicted to minimize export independence centrality relative to import independence.

In this paper we present results for two commodities -- industrial machinery and clothing or apparel -- selected from a series of commodities that we have been studying. From previous analysis (Smith and White 1988) we know that industrial machinery shows a five-block export hierarchy from core to periphery (with strong and weak peripheries and semiperipheries). We also hypothesize, based on previous work, that export of clothing or apparel is one of the key commodities in the mobility of countries in intermediate positions in the hierarchy. We expect the propositions advanced above to apply differently to different classes of commodities we expect to develop other hypotheses that cover other theoretical aspects of flow centrality as a factor in positional structure and positional mobility.

RELATION BEIWEEN IMRORT/EXRORT CENTRALITIES: NEED FOR CENTRALITY RATIOS

Table 3 shows correlational evidence farm the three time periods of our study -- 1965, 1975, and 1980 -- that corroborates and amplifies our

expectations about the relationships among the measures. There are three sets of results: (a) export and import betweenness are very strongly correlated (ranging between .967 and .999); (b) the correlation between maximum inflow and outflow is moderate (for all three periods and for both commodities, correlations range between .492 and .775); (c-d), the two dependence measures are moderately correlated (after eliminating outliers of zero dependencies due to zero flows), ranging between .546 and .823.

How can we explain the extremely close relation in Table 3a) between import and export betweenness when one is hypothesized to have positive effects for mobility, and the other negative effects? The moderate correlation between maximum inflow and outflow does not support the hypothesis that the correlation is due to the scale effect of even stronger correlations between exports and imports. Nor is our result in 3a) an artifact of the method. The close coupling of (advantageous) import betweenness and (disadvantageous) export betweenness could be a function of (1) positioning in the world economy, where higher import betweenness "forces" higher relative export betweenness due to at least partial reciprocity of trade, (2) differential terms of trade in which tariffs or export quotas alter the costs and balance between imports and exports, (3) differences in currency values, which also affect the balance between imports and exports, and/or (4) "unequal" exchange, in which favorable terms of trade accrue to countries in dominant positions in the world economy.

If any or all of these factors for the correlation of import and export betweenness are true, it would appear that an additional key to understanding these results is the ratio between import and export betweenness. Thus, (hypothesis 5) all countries are predicted to attempt to minimize the export/import betweenness ratio. But (hypothesis 6) relative positional advantages predict that countries ranking higher in position would have a

better chance to succeed in raising the ratio than lower ranked countries. And lower countries as the reciprocals to these terms of trade would be forced into a disadvantageous ratio.

REIATIONS BEIWEEN DIFFERENT TYPES OF CENTRALITY

Table 4 shows, for the relationships between different measures, that: (a) export flow are often proportional to (advantageous) import betweenness, with three out of four correlations ranging between .919 and .987 (clothing in 1970 is an exception with a correlation of .851); (b) low import flow is closely related to dependence on import brokers correlations for maximal import flow are between -.993 and -.965), and low export flow is closely related to dependence on export brokers (this helps to define the nature of peripherality in the world economy); (c) there is a moderate negative correlation for betweenness and dependence.

The overall association among these measures, for this dataset, is shown in Figure 6a. In the top row are the brokerage measures hypothesized to benefit growth: import betweenness, export maxflow, and export independence, with the first two strongly associated and the last somewhat more independent. In the bottom row are the dependency measures hypothesized to be detrimental: export betweenness, import maxflow, and import independence. Again, the last is somewhat more independent of the other two, but the first two elements are not as strongly correlated as in the first row. While all of these measures tend to be moderately to strongly correlated (either positively or negatively), they tap slightly different aspects of trade centralities and may be extremely useful in clarifying the empirical evidence and support for different conceptual hypotheses about growth and positional change in the world economy.

EMPIRICAL RELATION BEIWEEN WORLD ECONOMIC FOSITION AND FLOW CENTRALITIFS

Figures 7-18 show the empirical relation between world economic position

and three flow centralities for two time periods (1965 and 1970) for two commodities (industrial machinery and clothing), showing (a) imports, (b) exports, and (c), were relevant, the log of import/export ratios for the different measures of centrality.

Figures 7 and 8 show for 1965 and 1970 that: (a) consistent with the Adam Smith/Allyn Young conception of a vertical division of labor, where core countries are dependent on heavy industrial imports in order to become industrial exporters, the maximum flow of imports of heavy machinery is nearly linear with world economic position; (b) partly consistent with Wallerstein's (1974) model, but also with the concept that industrial exports are outcomes rather than determinants of position, the maxi1num flow of exports of heavy machinery is nonlinear with economic position, forming a distinct cluster of dominant countries with a large and, by 1970, a widening gap between them and the how exporters; (c) as countries compete for industrial imports needed for modern state economies and differentiate in exports of industrial manufactures, maxflow export/import ratios are higher in dominant positions (but only slightly positive) and lower (often highly negative) in the peripheries.

Weaker versions of these three patterns are found for maxflow imports and exports of clothing and, apparel in graphs (a-c) of Figures 9 and 10. Export/import ratios (pattern c), however, are neutral for the most dominant positions and may be either positive or negative in the semiperipheries, although largely negative in the peripheries. Clearly, the textile industries offer a potential source of upward mobility in economic position due to cheaper labor for light industries in the semiperipheries.

Figures 11 and 12 show for 1965 and 1970 that (a) countries with betweenness on the imports of others for industrial machinery (i.e., with high average dependencies of others on them, brokering to many others, and highly correlated with export flows in Figure 7b) form a distinct cluster of dominant

countries with a large and, by 1970, a widening gap between them and the majority of others; (c) countries in dominant positions avoid a surplus of export over import betweenness, but less dominant countries do not avoid the negative impact of this situation; (b) because of this "squeeze" toward the middle in export betweenness, this index of "negative" centrality is relatively strongly correlated with position.

A similar but weaker pattern is found for c1othirg and apparel in Figures 13 and 14. There is less constraint by position, and/or potential for mobility in relationships (a) and (b) between position and centrality.

Figures 15 and 16 show for 1965 and 1970 that (a) countries in more dominant positions avoid import broker dependence; (b) only a few core countries are able to do this at the same time as they swing towards higher export dependence; and (c) the ratios of export to import dependence are fairly random with respect to position.

An extremely weak pattern of the same type is found for clothing and apparel in Figures 17 and 18. Here there is again much less constraint by position.

EVALUATION OF PREDICTIONS ABOUT POSITION AND CENTRALITY

Hypotheses 1 and 2, that dominant countries will exhibit high import betweenness (export brokerage) but relatively lower export betweenness is strongly supported for industrial machinery (Figures 11-12) and moderately for clothing (Figures 13-14). Whereas only a few dominant countries avoid export betweenness for machinery (Figure 13c), many countries do for clothing (14c).

Regression analysis, however, suggests that it is industrial machinery maxflow imports that account for most of the variance in position (78% in 1965, 82% in 1970), followed by maxflow exports (an additional 11% and 8% of variance in 65 and 70). However, import betweenness *is* a close (and colinear) second in the regression analysis (74% and 78%), and maxflow imports

exports from clothing bring the variance in the betweenness model to 77% 81%. Both these analyses point to the same conclusion: that it is industrial imports, not exports, and brokerage via Adam Smith/Allyn Young's vertical division of labor, that are the predominant exchange centrality factors associated with positional dominance in the world economy.

Hypothesis 3, that dominant countries will avoid import broker dependence, is strongly supported for industrial machinery (Figures 15-16) and weakly for clothing (Figures 17-18). Hypothesis 4, that export brokerage will be sought relative to low import brokerage, is supported by evidence from only few core countries, but must be rejected on a broader statistical basis.

Hypotheses 5 and 6, that dominant countries will exhibit a low (advantageous) ratio of export to import betweenness and peripheral countries will be high and disadvantaged on this ratio, are borne out by Figures 11-14.

PREDICTING CHANGE

Mobility from the strong semiperiphery into the core in the expansionary period between 1965 and 1970, as shown in Figure 19, is predicted (71% variance) by one variable: a low ratio of export to import betweenness in clothing and apparel (Figure 19). This is the industry in which the semiperiphery, as we have noted, has considerable edge because of competitive wages. For 1970-80, the same variable accounts for 26% of the block 4 upward mobility (Figure 21), but 26% of the variance in block 2 mobility is also predicted, although in the opposite direction (Figure 20). This shift in the pattern of block 2 mobility may be the effect of the recessionary period, when wages go down in the core relative to the strong semiperiphery (hence they lose out by pursuing what was a successful strategy in the previous expansionary period), but relative wage advantages are now transferred to more peripheral positions such as block 4 (strong periphery). The ratio of maxflow exports to imports in clothing or machinery does not predict change for any of these periods or blocks of countries.

The same variable (ratio of export to import betweenness in clothing), that we hypothesized to be important to mobility both in terms of the type of centrality (betweenness) and the type of commodity (textiles), predicts 13% of the total simple variance in mobility for 1965-70 (Figure 22). But by itself it predicts very little of the total sample variance in mobility for 1970-80. Remembering that this period of time was recessionary, we add the avoidance of important dependence as an insulating variable against recession. Import dependence in clothing (Figure 23) predicts 15% of the variance (P=.001), with the export/import betweenness ratio predicting another 5% variance (p=.04). Together, these factors account for 36% of the variance in block 2 (strong semiperiphery) mobility.

Regression analyses of position mobility as predicted by flow centrality measures consistently support our hypotheses (following Schneider 1977, 1987) about the pivotal role of the clothing-textile-apparel industries in positional mobility in the world economy. For present purposes, in evaluating the new set of flow centrality measures, they offer a rather strong demonstration that the different kinds of flow centrality are well worth careful measurement, since they may lead to important substantive results, clarifications, and predictions about the mobility of states in the world economy.

ENDNOTES

1. The data for this project were developed at North Carolina by Roger Nemeth and David Smith and were prepared for a UCI mainframe computer system by Smith. From there, they were transferred to MS-DOS diskettes for further analysis by White. This work was supported by departmental research funds to the senior author from the Program in Comparative Culture, and an NSF grant for CRAY supercomputer computation of the regular equivalence of countries in the multicommodity world economy. Computation of centralities was done on IBM-compatible XT and AT systems. Thanks to Steve Borgatti who graciously modified his Pascal implementation of the Ford-Fulkerson algorithm to compute maximum network flows. That routine is available from Borgatti as part of his

AL (Algorithmic Language) package for network analysis. The mathematization and FORTRAN programming of the centrality algorithms was done by Douglas White, and the requisite programs are available from him and will be donated to the UCINET network analysis package. We also thank Sam Gi1more and Linton C. Freeman for helpful comments.

REFERENCES CITES

Cook, K. S., R. M. Emerson, M. R. Gil1more. 1983. The Distribution of Power in Exchange Networks: Theory and Experimental Results. American Journal of Sociology 89: 275-305.

Ford, L. R., and D. R. Fulkerson, 1962. Flows in Networks. Princeton.

Frank, A. G. 1969. Latin America: Underdevelopment or Revolution? New York.

-- 1978. World Accumulation: 1492-1789. New York.

-- 1979. Dependent Accumulation and Underdevelopment. London.

Freeman, L. C. 1978. Centrality in Social Networks: Conceptual Clarification. Social Networks 1: 215-239.

-- 1980. The Gatekeeper, Pair-Dependency and structural Centrality. Quality and Quantity 14(4): 585-592.

Galturg, J. 1971. A structural theory of Imperialism. Journal of Peace Research 2:81-117.

Kaldor, N. 1985. Economics without Equilibrium. New York.

Schneider, J. 1977. Was there a pre-capitalist World System? Peasant Studies 6: 20-29.

--- 1987. Clothing. Annual Reviews of Anthropology 1987.

Smith, A. 1776. The Wealth of Nations, book I.

Smith, D., and D. R. White. 1988. Structure and Dynamics of the Global Economy: Network Analysis of International Trade 1965-1980. Ms. Published 1992 Social Forces 70(4):857-893.

Wallerstein, I. 1974. The Modern World-System. New York.

White, D. R., and Karl Reitz. 1983. Graph and Semigroup Homomorphisms on Networks of Relations. Social Networks 5: 193-224.

Young, A. 1928. Increasing Returns and Economic Progress. Economic Journal.