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A THEORETICAL AND EMPIRICAL ANALYSIS OF TWO GRAVITY DETERMINISTIC INDUSTRIAL LOCATION MODELS

by

Marc Randolph Wiitala

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BY

Marc R. Wiitala

APPROVED	DATE
F. Charles Lamphear	Sept. 11, 1979
Theo. W. Roesler	Sept. 11, 1979
F. G. Hayden	Sept. 11, 1979
Roger F. Riefler	Sept. 11, 1979
James B. Hassler	Sept. 11, 1979

SUPERVISORY COMMITTEE

GRADUATE COLLEGE UNIVERSITY OF NEBRASKA

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INTRODUCTION

When first extended to the interregional system, input-output analysis was considered to have the potential of being used to analyze problems falling within the purview of general location and trade theory.[1] But subsequent development and empirical application of the interregional input-output framework did not take this direction. As noted by Roger F. Riefler, "rather than the interregional model providing a framework for a general location theory, causation ran the other way--the tools of location theory were used to reduce the stringent data requirements of the interregional model"[2] Instead, researchers were content with applying the techniques to other areas: interregional commodity flows, regional balance of payments, and impact analysis.[3]

In 1963, events in the evolution of interregional input-output analysis took a turn which provided the opportunity to revitalize the general location, theoretical aspects of this method of interregional analysis. In an attempt to formulate an interregional input-output

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[1]Walter Isard, "Interregional and Regional Input-Output Analysis: A Model of the Space Economy," The Review of Economics and Statistics, 33 (November, 1951), 305-20.

[2]Roger Riefler, "Interregional Input-Output: A State of the Arts Survey," Studies in Economic Planning Over Space and Time, ed. George G. Judge and Takashi Takayama (Amsterdam: North-Holland Publishing Company, 1973), p. 153.

[3]Charles M. Tiebout, "Regional and Interregional Input-Output Models: An Appraisal," Southern Economic Journal, XXIV (1957), 142-43.

model which would circumvent the stringent commodity flow data requirements of previous models, Leontief and Strout introduced a gravity trade submodel which permitted endogenous determination of interregional commodity flows while allowing gross crosshauling of commodities between regions.[4] The gravity model linked regions in a manner which made the flow of commodities between regions dependent only on the total demand for and supply of a given commodity in the importing and exporting regions, respectively, according to

$$(1)\quad {}_{rs}X_i = \frac{({}_rX_i)({}_sU_i)}{X_i}\,{}_{rs}Q_i$$

where ${}_{rs}X_i$ represents the shipments of commodity i from region r to region s; ${}_rX_i$ and ${}_sU_i$ symbolize, respectively, total production and consumption of good i in regions r and s; X_i indicates total production of i in all regions; ${}_{rs}Q_i$ is a multiplicative constant.

From the viewpoint of location theory the most interesting aspect of the Leontief-Strout gravity model is the multiplicative constant, ${}_{rs}Q_i$, which can be established for any pair of regions given the values of the other variables in the structural equation. This multiplicative constant was suggested by Leontief and Strout to characterize "the structure of the interregional flows" in terms of the effects of both spatial proximity between regions and "in a summary way the relative position of region r vis a vis all other regions as a supplier, and of region s as a user, of good i."[5] However, since

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[4]Wassily Leontief and Alan Strout, "Multiregional Input-Output Analysis," Structural Interdependence and Economic Development, ed. Tibor Barna (New York: St. Martin's Press, 1963), pp. 119-23.

[5]Ibid., p. 129.

their objective was primarily to develop and operationalize an interregional input-output model with limited data requirements, Leontief and Strout did not extensively explore, beyond the influence of the spatial element, the underlying dimensions of the multiplicative constant.

That the constant contained, in terms of information content, a potential avenue for investigating the manner in which relative regional environmental conditions influence, via their effect on interregional commodity movements, the level and location of industrial production did not go unnoticed. Suggesting the multiplicative constant be labeled as a location coefficient, Riefler recognized the subtle link between the Leontief-Strout input-output model and location theory inherent in the gravity trade submodel when stating

> . . . Although originally formulated as an approximation to the ideal Isard interregional model, the Leontief-Strout model, through the use of the location coefficient . . ., contains an implicit location theory.[6]

As Riefler states later, the location coefficient

> . . . should facilitate the identification, at a moment in time, of the locational 'sensitivity' of each industrial sector to the availability of local markets and local inputs, agglomeration economies, as well as the industry's access to dispersed markets and transferable inputs.[7]

In this sense the location coefficient is a measure of structure: the complex set of locational relationships that gives rise to the level of commodity movement between two regions. Thus, the location coefficient will be different for every pair of regions, and, since trade structure

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[6]Riefler, op. cit., p. 155.

[7]Ibid.

is continually undergoing change, for any pair of regions the location coefficient, while constant at a moment in time, will change over time. For these reasons the location coefficient will be more characteristically referred to as a parameter rather than as constant with its implication of invariance.

The key to refining the capabilities of the gravity model as a means for capturing regional interdependencies, whether the model is used in conjunction with an interregional input-output model or on its own merit as a tool for location and trade analysis, depends to a major extent on identification of the underlying dimensions of the location coefficient. In this regard Riefler suggested that adjustment of the Leontief-Strout model to incorporate the effect of variations in spatial proximity and/or agglomeration economies would produce a location coefficient more sensitive to the availability of local inputs (or more generally relative regional environmental conditions).[8] Research along this avenue was later conducted by Riefler and F. Charles Lamphear.[9] Focusing on the basic ferrous metals industry and trade in 1967 between the 25 selected production areas defined by the United States Department of Transportation, they investigated in one phase of their research the consequence of adjusting the Leontief-Strout gravity framework in the following manner:

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[8]Ibid., see footnote 18, pp. 155-56.

[9]Roger F. Riefler and F. Charles Lamphear, "An Empirical Deterministic Model of Industrial Location," Journal of Regional Science, 17 (August, 1977), 357-67.

$$(2)\quad {}_{rs}X_i = \left[\frac{({}_rX_i - {}_rU_i^c)({}_sU_i - {}_sX_i^c)}{(X_i)(D_{rs})}\right]{}_{rs}\bar{L}_i$$

where all terms used previously are defined as before; ${}_rU_i^c$ denotes the total input of i in region r into some defined complex of industries consuming good i; ${}_sX_i^c$ indicates the total output of good i in region s; ${}_{rs}\bar{L}_i$ is the new location coefficient generated by the adjusted gravity framework; D_{rs} represents the distance between regions r and s, and serves as a proxy for the cost of transporting goods between regions.

Utilizing a rank correlation testing procedure, Riefler and Lamphear offered evidence substantiating their hypothesis that the location coefficient generated by their gravity model provides a better measure of the regional environmental conditions reflecting the relative attractiveness between two regions for industrial location.[10] While the rank testing procedure used by them supported their contention, it was only an indirect test. Conclusive results would be forthcoming only if the adjusted location coefficient showed greater association with a given set of relative locational factors than that exhibited by coefficients generated by other gravity models.

OBJECTIVES

The entire question of whether the gravity framework can be used as a tool for industrial location analysis hinges on the hypothesis that the empirical parameters generated by the model are related to a set of variables measuring the influences of relative regional environmental conditions on commodity interaction. Riefler and Lamphear

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[10]Ibid., p. 360.

assumed the existence of this association as true and proceeded to refine the Leontief-Strout gravity framework to provide a more sensitive measure of the relationship implied by the above hypothesis. However, neither the validity of this assumption nor the general composition of the environmental conditions have been firmly established either empirically or theoretically. In fact, there has been a paucity of discussion at the conceptual level about how the gravity model is related to the more general body of interregional trade and location theory.[11]

The research conducted by Riefler and Lamphear in determining the efficacy of using the gravity framework as a tool for industrial location can best be described as both exploratory and inductive in nature. This explains to a large degree the absence of a strong and explicit theoretical framework supporting their line of research. Furthermore, their research results, as noted earlier, were not conclusive but offered only partial evidence supporting the contention that the empirical constant produced by their gravity model exhibits greater locational sensitivity than that of the Leontief-Strout model, even when both are adjusted for distance.

The general purpose of this research project is to provide further evidence of the usefulness of the gravity framework as a vehicle for studying the influence of relative regional location conditions, whether economic or otherwise, on the level and location

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[11] At the international level a rather extensive treatment of the relationship between the gravity trade model and general economic theory has been provided for consumptive commodities by Hans Linneman, An Econometric Study of International Trade Flows (Amsterdam: North-Holland Publishing Company, 1966), pp. 37-56.

of industrial production. In extending the work of Riefler and Lamphear in the basic ferrous metals industry, the more specific objectives are:

1. To provide a conceptual basis for using the gravity model as a tool for location analysis.

2. To provide some empirical evidence on the existence and composition of the underlying locational dimensions of the distance adjusted location coefficient generated by a gravity trade model.

3. To compare the sensitivity of the location coefficients produced by the Leontief-Strout and Riefler-Lamphear gravity models to a set of selected variables measuring the influence of regional locational conditions on the location and level of regional production.

The first objective will be achieved by reviewing basic gravity concepts and evaluating the gravity trade models considered in this study within the context of location and trade theory. Achieving this objective will enhance the insight needed to develop the structural and substantive forms of the models utilized in the empirical analysis and will provide a strong basis from which to interpret and evaluate the empirical results. Attainment of the second objective will be made by empirically determining if the location coefficients are related to a set of relative locational conditions. The third objective will be achieved by comparing how well the set of variables selected to measure the influence of relative regional locational conditions on the location and level of regional production account for the variability exhibited in the Leontief-Strout and Riefler-Lamphear location coefficients.

SCOPE OF STUDY

The investigation conducted here is primarily an extension of the pioneering research of Riefler and Lamphear; consequently, the scope of this study is limited to the same general domain as found in their research. The industry selected for the empirical analysis can be roughly defined as the basic ferrous metals industry. This industry is characterized according to the Standard Industrial Classification (S.I.C.) code established by the United States Bureau of Commerce as S.I.C. 33 minus S.I.C. 335. The former industry is composed of the entire primary metals industry while the latter constitutes the greater portion of the nonferrous metals industry. Those industries considered to be part of the industrial complex and the major consumers of basic ferrous metal products are the fabricated metals and machinery industries as defined by S.I.C. codes 34 through 36.

The study is limited to the year 1967. Geographically, the scope of analysis centers around the 25 production areas defined in 1967 by the United States Department of Transportation, a list of which is given in Table 1. These regions account for about 80 percent of total production in the basic ferrous industry.

PLAN OF STUDY

This section briefly sets forth the plan of study as contained in the following chapters. Chapter 2 comprises a review of gravity concepts in the social sciences. Considerable attention is given to the probability rationale for this type of interaction model.

Table 1

Department of Transportation
Selected Production Areas

Production Area	Constituent Standard Metropolitan Statistical Areas
1	Boston, Brockton, Lowell, and Worcester, Mass.; Lawrence-Haverhill, Mass.-N.H.; and Providence-Pawtucket-Warwick, R.I.-Mass.
2	Bridgeport, Hartford, Meriden, New Britain, New Haven, Norwalk, Stamford, and Waterbury, Conn.; and Springfield-Chicopee-Holyoke, Mass.-Conn.
3	New York, N.Y.
4	Jersey City, Newark, and Paterson-Clifton-Passaic; and Middlesex and Somerset counties, N.J.
5	Philadelphia, Pa.-N.J.; Wilmington, Del.-N.J.-Md.; and Trenton, N.J.
6	Baltimore, Md.
7	Allentown-Bethlehem-Easton, Pa.-N.J.; and Reading, Pa.
8	Harrisburg, Lancaster, and York, Pa.
9	Albany-Schenectady-Troy, Syracuse, and Utica-Rome, N.Y.
10	Buffalo and Rochester, N.Y.
11	Akron, Canton, Cleveland, Lorain-Elyria, and Youngstown-Warren, O.; and Erie, Pa.
12	Pittsburgh, Pa.; and Steubenville-Weirton and Wheeling, O.-W. Va.
13	Ann Arbor, Detroit, and Flint, Mich.; and Toledo, O.-Mich.
14	Dayton, Hamilton-Middletown, and Springfield, O.; and Cincinnati, O.-Ky.-Ind.
15	Chicago, Ill.; and Gary-Hammond-East Chicago, Ind.
16	Kenosha, Milwaukee, and Racine, Wis.
17	Minneapolis-Saint Paul, Minn.
18	Saint Louis, Mo.-Ill.

Table 1 (continued)

Production Area	Constituent Standard Metropolitan Statistical Areas
19	Atlanta, Ga.
20	Dallas and Fort Worth, Tex.
21	Beaumont-Port Arthur, Galveston-Texas City, and Houston, Tex.
22	Denver, Colo.
23	Seattle-Everett and Tacoma, Wash.
24	San Francisco-Oakland, San Jose, and Vallejo-Napa, Cal.
25	Anaheim-Santa Ana-Garden Grove, Los Angeles-Long Beach, and San Bernardino-Riverside-Ontario, Cal.

Source:

Dale W. Dison and Carl W. Hale, "Gravity versus Intervening Opportunity Models In Explanation of Spatial Trade Flows," Growth and Change, October, 1977, p. 16.

Chapter 3 provides the conceptual framework for the entire study. Since this research project is primarily an extension of the pioneering work of Riefler and Lamphear, an extensive review is given here to their research. This chapter also discusses the relationship between gravity trade analysis and the more general body of interregional trade and location theory. Particular attention is paid to the use of the Leontief-Strout and Riefler-Lamphear models for location analysis.

Chapters 4 and 5 are concerned with the empirical aspect of the study. In Chapter 4, the model used to determine the presence of locational dimensions underlying the location coefficients and compare the sensitivity of the location coefficients generated by the Leontief-Strout and Riefler-Lamphear gravity models is presented. The methodology for estimating the relationships posited by the models is set forth in Chapter 5.

Chapter 6 presents and evaluates the empirical results. Particular attention is given to evaluating the location analytic potential of the gravity trade framework on the basis of the precepts posited in the theoretical chapter--Chapter 3. Both gravity frameworks are compared in this capacity. The limitations of the study and directions for further research are also presented.

The final chapter, Chapter 7, summarizes the entire study. The objectives are reiterated; the method used to achieve the objectives is set forth; the findings and conclusions are restated.

Chapter 2

GRAVITY CONCEPTS IN THE SOCIAL SCIENCES

The formula for gravity encountered in the science of physics has provided on occasion the basis for constructing models for spatial interaction of economic, social, and political phenomena. The theoretical framework underlying these models has not been well developed; consequently, these gravity models, as they are usually named, have been used in descriptive and predictive capacities rather than being offered as explanations of behavior. As empirical tools, gravity models have been employed to study the resistive influence of spatial, cultural, and educational differences on interactive processes existing between various segments of our environment.[12] However, when an attempt is made to understand the interaction processes modeled by gravity concepts, an appeal must be made to more general and established bodies of theory.

The purpose of this chapter is to briefly review the development of the gravity model as applied in the social sciences. Particular emphasis is given to those areas of development which will facilitate understanding of the theoretical propositions set forth in subsequent chapters.

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[12]Walter Isard, Introduction to Regional Science (Englewood Cliffs: Prentice-Hall, Inc., 1975), p. 45.

HERITAGE OF A SOCIAL INTERACTION MODEL

Through the years numerous analytical frameworks have been formulated to study social and economic processes. While most of these models were grounded in well developed bodies of social and economic theory, some were borrowed from other sciences. An example of this transfer of methodology from one field of study to another can be found in the work of the Social Physicists. In this instance the transfer of knowledge was initiated by natural scientists. The Social Physicists applied the concepts of gravitational force, energy, and potential to social interaction in a manner analogous to the physicist's analysis of interaction between masses. As noted by Erling Olsen, the Social Physicists ". . . found it rewarding to regard members of a social group as the individual molecules of physical mass and to analyze the interaction between social groups in the same way as the physicists analyze interaction between masses."[13]

Although the presence of gravitational force in social phenomena was observed as early as the mid-nineteenth century by H.C. Carey and modeled in the area of retail trade by W.J. Reilly in 1929, not until the empirical works of J.Q. Stewart and George K. Zipf in the 1940s were physical concepts of interaction extensively used to study social phenomena.[14] Stewart retained the exact gravity and potential models used in physics for his examination of social

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[13]Erling Olsen, International Trade Theory and Regional Income Differences (Amsterdam: North-Holland Publishing Company, 1971), p. 14.

[14]Ibid.