This is to certify that the

thesis entitled

SPATIAL INTERACTION
AND
THE NORTH AMERICAN FREE TRADE AGREEMENT

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Chapter One

INTRODUCTION

Statement of Problem

The North American Free Trade Agreement (NAFTA) was implemented in 1994 with the objective of eliminating trade barriers; facilitating cross border movement of goods and services; promoting conditions of fair competition; and increasing investment opportunities among the United States, Mexico and Canada (Pastor, 1993; Huffbauer and Schott, 1992). Even before its inception, scholars debated the potential outcomes of NAFTA. Proponents and opponents of the agreement alike predicted that the pact would have a profound impact on the economies of participating nations (Krugman, 1993).

Patterns of trade since 1994, however, have corroborated the assessment of a relative minority of experts who asserted that NAFTA's impact on the North American economy would be negligible (Lustig et al., 1992; Krugman, 1993). The consensus among economists is that NAFTA has not resulted in significant changes in the volume of trade nor the composition of trade among participating nations (Hinojosa-Ojeda, 1996). This thesis will assess the impact of NAFTA from a geographic perspective by examining changes in spatial interaction between the United States and Mexico since 1993. Trans-border trade between the two countries will be used to evaluate changes in the geographic structure of trade, as well as changes in the relative accessibility of places that generate and attract trade.

Background

Although NAFTA differs from previous free trade initiatives in joining countries at widely different stages of economic development, the agreement advances a process of economic integration that began more than a decade ago (Chavez and Whiteford, 1996; Lustig et al., 1992). Following the balance of payments crisis and external debt debacle of the early 1980s, Mexico undertook a series of dramatic economic reforms, including trade and financial liberalization and currency devaluation. These measures culminated in the country's incorporation to GATT in 1986.

The rapid inflow of capital following Mexico's entry to GATT was accompanied by a tremendous increase in the volume of trade, as well as a significant transformation in the composition of trade. In the early 1980s, manufactured goods made up less than 20 percent of Mexico's total exports and intermediate goods accounted for approximately one-half of its imports. By the early 1990s, however, intermediate goods and manufactured products comprised more than 80% of the total value of both Mexican imports and exports, respectively (Hinojosa-Ojeda, 1996).

Many of the trade liberalization measures associated with NAFTA had already been implemented by the time the agreement was ratified. In fact, in the case of Mexico, economic reforms were much more drastic than those imposed by NAFTA. With Mexico's admission to GATT, maximum import tariffs declined from 100 percent to 20 percent. By the time NAFTA was conceived, average US tariffs on Mexican goods had fallen to 3.9 percent and the average Mexican tariff was about 10 percent. Following the inception of NAFTA, average tariffs declined to an average of 1.5 percent for the United States and 5 percent for Mexico (Pastor, 1993; Hinojosa-Ojeda, 1996).

Not coincidentally, North American trade has become increasingly concentrated over the past decade. Since 1986 US exports to Mexico have increased three times faster than exports to the rest of the world; by 1989 half of US trade with Latin America was with Mexico alone. In the case of Mexico, the volume of imports and exports began to increase rapidly following 1988, nearly quadrupling by 1996 (Hinojosa-Ojeda, 1996).

Notwithstanding the increasing volume of trade between the United States and Mexico, the importance of each country as a trading partner varies greatly. Though the United States is the recipient of more than 80 percent of Mexico's exports, US exports to Mexico generally comprise only 5 to 7 percent of the country's total exports (Pastor, 1993; Hinojosa-Ojeda, 1996).

Trade between the United States and Mexico is largely dependent on surface modes of transportation. During the 1990s more than 90 percent of the total value of imports and exports has been transported by truck or rail. Furthermore, trade between the two countries is extremely concentrated. Five US states (Texas, California, Arizona, Michigan and Illinois) regularly account for more than two-thirds of total exports to Mexico. Likewise, five locations in Mexico (Mexico City, Chihuahua, the state of Mexico, Baja California Norte and Tamaulipas) receive about 60 percent of all exports from the US (Nozick, 1996).

Although Mexico is the United States' third leading trade partner, a significant portion of trade between the two countries involves intra-firm transactions, comprised of raw materials, parts and intermediate goods. For instance, two commodity groups – machinery and transportation/vehicles – comprise almost one-half of the total value of exports to Mexico. The vast majority of trade within these commodity groups is composed of intermediate goods destined for assembly in Mexican maquiladora plants and subsequent re-entry to the United States. When the movement of intermediate goods is accounted for, the volume of US-Mexico trade is reduced substantially, perhaps by more than 60 percent. When trade in intermediate goods is eliminated, Mexico falls to the United States' sixth leading trade partner (Nozick, 1996).

Assessment of NAFTA

From an economic perspective, the purpose of NAFTA is to advance an integrative process that began with labor flows following World War II and accelerated with Mexican economic liberalization in the 1980s (Haggard, 1995). Starting with Mexico's Border Industrialization Program (BIP) in 1965, however, integration was largely restricted to manufacturing activities along the US-Mexico border. The agreement is expected to build on each participating nation's comparative advantage; make each country's industrial base more efficient and competitive; and generate substantial new trade, investment, employment and growth (Huffbauer and Schott, 1992).

Some experts believe that high rates of growth in Mexico would expand North American trade and spread benefits throughout the entire continental economy. Potential benefits include the reduced flow of undocumented immigrants and an increase in the demand for US manufactured and luxury goods (Lustig et al., 1992).

The United States is expected to export more agricultural products and processed foods, chemical products, capital goods, transportation equipment and automobiles. Mexico is likely to export more fruits and vegetables, textiles and durable goods. The Mexican economy, because it is smaller and more dependent on US trade, is expected to gain the most; the impact of NAFTA on the US economy is not expected to be very profound (De Janvry et al., 1997; Krugman, 1993).

From a geographic perspective, however, the agreement will promote greater spatial interaction by improving transferability among the nations of North America, reducing the effort (in time and costs) required to overcome distance and decreasing the role that distance plays in impeding interaction. If its economic objectives are fulfilled, NAFTA will also result in greater complementarity (expressed in terms of increased supply and demand) among the United States, Canada and Mexico. The purported benefits of NAFTA, however, will vary among nations, regions of individual countries, and sectors of those national and regional economies. Changes in spatial interaction as a consequence of the agreement will impact, to varying degrees, the relative accessibility of places that generate and attract trade (geographic structure of trade), as well as the role of distance in impeding the movement of specific goods (commodity structure of trade) by different modes of transportation.

Though many experts believe that NAFTA will have a positive impact for all countries in terms of increased trade, investment, employment and growth, some scholars contend that the benefits of free trade that come about quickly in theory are realized more slowly in reality due to differences in economic and population size and the role of multinational corporations (the Mexican maquiladora industry).

Grinspun and Cameron (1993) assert that NAFTA will no doubt promote rapid economic growth in certain regions of North America. However, they assert that the regional dominance of the United States and asymmetries in power, wealth, technology and cultural influence guarantee that benefits and costs will be distributed unequally within and among participating countries. In addition, they emphasize the importance of other elements, such as changes in income distribution, the effects of investment flows and increased capital mobility, and differences between countries in institutional, social and political structures in assessing the potential outcomes of the agreement.

Hanink (1994) emphasizes the relevance of both the geographic and commodity structures of trade in assessing NAFTA. He affirms that changes in the commodity structure of trade and geographic structure of trade (spatial flows of goods) result from the potential increase in actual and perceived benefits to trading partners. Trade flows are affected by place characteristics, or a country's domestic economy; however, place characteristics are also affected by the flow of goods (Hanink, 1994). Regional disparities will likely be influenced by changes in accessibility and the role of distance in impeding interaction. Regions endowed with better access will benefit from NAFTA; declining relative accessibility will indicate locations that are becoming less competitive.

In the context of the North American Free Trade Agreement, trans-border trade between the United States and Mexico offers empirical evidence of the relationship between the commodity and geographic structures of trade, as well as spatial interaction and economic development. Policies such NAFTA seek to achieve economic development, in part, by expanding trade among member nations. Trade, the movement of goods between places on the basis of comparative advantage and factor endowments, is a traditional focus of economic geography and spatial interaction.

In order to assess the impact of NAFTA, the role of distance in impeding trade must be quantified. In an international context, the friction of distance that constrains spatial interaction is comprised of two components – the impedance resulting from spatial separation and the barriers that exist and costs that are incurred when movement takes place across international borders (Keeble, 1985; Batten and Nijkamp, 1990).

The traditional gravity model can be applied to trans-border trade between the United States and Mexico to evaluate changes in the friction of distance and the relative accessibility of places in both countries. In the absence of government intervention, the friction of distance is thought to be relatively stable over short periods of time. At least in the short-term, then, any significant changes in spatial interaction and the friction of distance between the United States and Mexico can be attributed to the impact of NAFTA.

Research Objectives

The purpose of this thesis is to establish, both theoretically and empirically, the relationship between national policies that promote economic integration and changes in spatial interaction. By examining this relationship explicitly, this thesis seeks to derive a geographic basis for evaluating the impact of policies, such as NAFTA, that promote the interdependence of national economies.

A geographic basis for policy evaluation is essential because economic analyses typically focus on changes in the commodity structure of trade, overlooking unintended consequences in the geographic structure of trade. In addition, though economic analyses identify changes in the composition of trade and aggregate costs and benefits, they fail to identify changes in the relative accessibility of places that attract and generate trade and how the process of economic integration reduces the "barrier effect" of international borders and the friction of distance.

Changes in complementarity between the United States and Mexico following implementation of NAFTA will be examined using binary matrices to indicate the presence or absence of trade flows between states of each country. Matrices will be obtained to assess the overall complementarity of specific origins and destinations, as well as complementarity in each of ten commodity groups. Row sums will indicate the level of complementarity for each trade origin in the United States; column sums will indicate the demand of specific commodities generated by individual Mexican states. Matrix totals for 1994 and 1997 will be tested statistically to discern if significant changes have occurred in complementarity since the inception of NAFTA.

Traditional gravity models will be used to examine changes in transferability between 1993 and 1997. Changes in the role of distance in impeding trans-border commodity flows will be evaluated by mode of transportation and commodity type. In addition, the relative accessibility of trade origins and destinations will be quantified by examining changes in distance decay parameters of the models. Total-constrained gravity models are proposed to assess changes in the overall friction of distance between the two countries. Origin and destination-specific gravity models will be used to identify changes in the accessibility of places that generate and attract trade.

Hypotheses

In general, a greater level of interaction is expected between the United States and Mexico following implementation of NAFTA. In addition, the overall impact of distance in impeding spatial interaction is expected to decline as a consequence of the agreement. However, the magnitude of distance decay parameters is expected to vary depending on relative location, type of commodity and mode of transportation. Changes in the impedance of distance are also likely to vary based on location, commodity type and mode.

In general, the friction of distance of both trade origins and destinations is expected to be greater for peripheral locations in both the United States and Mexico. More central locations (both economically and geographically) are expected to display less sensitivity to distance. Furthermore, intermediate goods and liberalized products are expected to exhibit lower distance decay exponents than non-intermediate goods and commodities subject to taxes, respectively. Although prior research suggests that rail shipments tend to display somewhat less sensitivity to distance than commodity movements by truck, in the case of US-Mexico trade, commodity movements by truck are likely to exhibit lower levels of distance deterrence due to the overwhelming share of trade that is moved by truck and large inefficiencies in the Mexican rail system.

NAFTA is not expected to impact places that generate and attract trade uniformly. Because peripheral locations are expected to be more sensitive to distance, NAFTA likely will result in the most substantial reductions in the friction of distance among economically and geographically peripheral states in both countries.

Changes in distance decay parameters will also vary significantly by commodity type and mode of transportation. Since intermediate goods are generally free from tariffs and already experience high levels of interaction, the greatest changes in the friction of distance are likely to occur among non-intermediate goods. Furthermore, due to the reasons mentioned above, liberalized goods should also display lower distance decay exponents following NAFTA than goods that are still subject to taxes. Finally, any reduction in the friction of distance for different modes of transportation most likely will favor shipments by truck rather than rail.

In order to test the above hypotheses, the following formal null hypotheses are posited in this thesis:

- Total complementarity between US and Mexican states has not increased significantly since 1994 (1).
- Complementarity between the United States and Mexico in each of ten commodity groups has not increased significantly since 1994 (2).
- No significant decreases have occurred in the overall friction of distance between the two countries for 1993 and 1997 (3).
- No significant differences exist in the friction of distance for peripheral states and non-peripheral states for either 1993 or 1997 (4).
- Changes in the distance decay exponents of peripheral states between 1993 and 1997 are no different from changes in exponents of non-peripheral states (5).
- No significant decreases have occurred in the distance decay exponents of intermediate goods between 1994 and 1997 (6).
- No significant decreases have occurred in the distance decay exponents of non-intermediate goods between 1994 and 1997 (7).
- No significant decreases have occurred in the distance decay exponents of liberalized goods between 1994 and 1997 (8).

- No significant decreases have occurred in the distance decay exponents of non-liberalized goods between 1994 and 1997 (9).

- No significant decreases have occurred in the distance decay exponents of commodity shipments by rail between 1993 and 1997 (10).

- No significant decreases have occurred in the distance decay exponents of commodity shipments by truck between 1993 and 1997 (11).

- No significant differences exist in the friction of distance for intermediate versus non-intermediate goods for 1994 (12).

- No significant differences exist in the friction of distance for intermediate versus non-intermediate goods for 1997 (13).

- No significant differences exist in the sensitivity to distance of liberalized versus non-liberalized goods for 1994 (14).

- No significant differences exist in the sensitivity to distance of liberalized versus non-liberalized goods for 1997 (15).

- Distance decay exponents for commodity shipments by truck are not significantly less than distance exponents for shipments by rail for 1993 (16).

- Distance decay exponents for commodity shipments by truck are not significantly less than distance exponents for shipments by rail for 1997 (17).

Chapter Two

LITERATURE REVIEW

Spatial Interaction

The term "geography as spatial interaction" was coined by E.L. Ullman more than 40 years ago to describe the interdependence between geographic regions; it encompasses any movement over space that results from a human process (Ullman, 1980; Haynes and Fotheringham, 1984). Defined as the movement of goods, people, money and information, spatial interaction considers both site (local, underlying areal conditions) and situation (the interrelationships between places). As a result, though spatial interaction is clearly a function of place characteristics, it is also a product of the degree of spatial integration within a system of places (Ullman, 1980; Hanink, 1994).

According to Ullman, the bases for spatial interaction are complementarity, supply and demand considerations derived from areal differentiation, economies of scale and comparative advantage; intervening opportunity, the existence of complementary supply sources; and transferability, the costs of transportation and the effort required to overcome the friction of distance. Spatial interaction recognizes the distorting influence of political control and can be used to understand, or predict, potential new interaction under changed conditions, including policies such as NAFTA that promote increased economic interdependence (Abler et al., 1971; Ullman, 1980).

From a geographic perspective, spatial interaction is the process through which economic development is achieved. The relationship between spatial interaction and economic development is dynamic and mutually reinforcing. Economic development is the result of increased specialization and specialization is only possible through spatial interaction (Fotheringham and O'Kelly, 1989).

The Basic Gravity Model

The gravity model is the most widely used spatial interaction model and one of the earliest models applied in the social sciences. Carey introduced the logical basis for the relationship between gravity and human interaction in the second half of the 19th century; it was first applied by Ravenstein near the turn of the century in studying migration between English cities (Taaffe et al., 1996; Lowe and Moryadas, 1975). Gravity models attempt to describe the two most obvious factors affecting the amount of flow or interaction between any two locations – scale impacts (population, for example) and distance (Taaffe et al., 1996; Haynes and Fotheringham, 1984).

The gravity model assumes that two places interact with each other in direct proportion to the product of their masses and inversely proportional to some function of the distance between them. Interaction is defined as proportional to the trip generating capacity of the location where the trip begins and the attraction capacity of the location where the trip ends. In addition, the volume of flows decreases as distance or some other measure of spatial separation increases:

$$I_{ij} = \frac{P_i P_j}{d_{ij}} \qquad (1)$$

where: I_{ij} = the amount of interaction between places i and j during some period of time;
d_{ij} = some measure of spatial separation between places i and j
P_i, P_j= some measure of attraction between pairs of interacting places i and j

Gravity models are particularly useful in assessing two of Ullman's bases for interaction: complementarity and transferability. In addition, the model has been refined over the past 50 years to permit inclusion of the attributes of origins and destinations, spatial structure, and intervening opportunity.

Since its appearance in the social sciences literature more than a century ago, the gravity model has been used successfully to study international trade (Linnemann, 1966; Yeates, 1969) and commodity flows (Black, 1971; 1974); assess the impact of international borders on telecommunications (Mackay, 1958; Rietveld, 1993); delineate market area boundaries; explain migration patterns; and model urban land use (Lowry, 1964) and the urban transportation system. Though the model has been criticized for its lack of a sound theoretical basis, its continued use results from its surprisingly high degree of statistical explanation and empirical validation (Wilson, 1970).

Propulsive and Attractive Forces

The definition of attractive and propulsive forces (the P_i and P_j terms of the model) depends largely on the context in which the gravity model is applied. For example, labor surplus and number of unfilled job opportunities have been used in studies of migration and retail floor space has been utilized in retail market potential studies. Due to their availability, however, population and income figures (such as gross domestic product) are the two most commonly used measures of propulsive and attractive forces. Since population and income variables may conceal important differences between places, they may be weighted to account for variations in population characteristics such as income, education and gender; accommodate cultural and economic differences; and recognize the different contribution made by different regions to interaction potential. Propulsive and attractive forces may also be raised to some exponential power to control for size or agglomerative effects of population or economic activity (Haggett, 1977; Lowe and Moryadas, 1975; Desta, 1988):

$$I_{ij} = \frac{P_i^{\alpha} P_j^{\lambda}}{d_{ij}} \tag{2}$$

where: I_{ij}, P_i, P_j and d_{ij} are as above, and
α and λ are weights or exponents

The Potential Model

Another method of accounting for differences in propulsive and attractive forces is the potential model. The concepts of population and market potential were pioneered by Warntz (1959) and Harris (1954), respectively. Potential is a weighted measure of centrality or accessibility within a set of spatial nodes and can be thought of as a measure of the proximity of a given location to all other places in a spatial system.

The potential model is frequently used when the researcher is concerned with flows between one origin and many destinations. Whereas the gravity model is based on the assumption that the interaction between two places is related to the product of propulsive and attractive forces divided by the distance between them, the potential model quantifies interaction by summing the total interaction between a given place and all other areas (Dicken and Lloyd, 1990; Lowe and Moryadas, 1975):

$$V_i = \sum \frac{P_j}{d_{ij}} \tag{3}$$

where: $V_i =$ total potential at place i
$P_j =$ the size of another place in the region
$d_{ij} =$ the distance separating places i and j

When potential is computed for a large number of points in a region, a map of a potential surface can be constructed. Potential represents a force underlying interaction between places; like the gravity model, the basic population potential model can be weighted by income or retail sales model depending on the focus of a given study (Dicken and Lloyd, 1990).

The potential measure also can be used to calculate regional accessibility to economic activity. Economic potential, achieved by weighting population potential by income or gross state product (GSP), is a measure of accessibility to economic activity; this model can be interpreted as the volume of economic activity a region has access to after accounting for the cost of covering the distance to that activity. As a summary measure, it identifies disparities in accessibility between regions of high and low economic potential. A high relative accessibility conveys a comparative advantage and reduced distance costs. In addition, the modified potential model can be used to illustrate how regional accessibility to economic activity has changed over time (Abler et al., 1972; Keeble, 1980).

Friction of Distance

Euclidean distance, transportation costs or transportation time are most commonly used to quantify the role of spatial separation in impeding spatial interaction. In many instances, the distance decay term is raised to an exponential power to reflect the varying negative influence of distance on interaction. This exponent is generally determined empirically:

$$I_{ij} = \frac{P_i^{\alpha} P_j^{\lambda}}{d_{ij}^{\beta}} \tag{4}$$

where: P_i, P_j, d_{ij}, α and λ are as above, and
β is an empirically derived exponent

Although the gravity model assumes that the effect of distance varies smoothly and continuously over space, many applications of the model have revealed a substantial variation in the magnitude of distance decay parameters. Losch (1954), Mackay (1958), and Rietveld (1993), for instance, have demonstrated that international borders create significant discontinuities in patterns of interaction among places in different political territories.

Analyzing bank deposits along the US-Mexico border, Losch (1954) revealed that political barriers result in the truncation of spatial interaction, producing an effect identical to that of increasing the distance between interacting areas (Batten and Nijkamp, 1990). Though Losch does not explicitly employ the gravity model in this study, he illustrates how political and natural boundaries, reinforced by tariffs, theoretically should result in reduced spatial interaction.

Mackay (1958), in his analysis of international and interregional telephone calls in Ontario, Canada, demonstrates that international political boundaries create discontinuities in the patterns of spatial interaction among places in different political territories. By plotting distance decay parameters for several forms of movement across borders and comparing them to values for flows in a borderless environment, Mackay also assesses the displacement in spatial interaction due to the discontinuous friction of political boundaries. His research reinforces the utility of gravity and potential models in assessing the discontinuities created by international borders.

Rietveld (1993), in a study of barrier effects and transportation and communication networks in Europe, reveals that international borders exert a significant influence on telecommunication flows. Using a modified gravity model with a "reduction factor," he finds that telecommunication interactions between European nations are 60 to 70 percent less than the interaction that would be expected in the absence of borders. He attributes this reduction not to increased tariffs, but to the fact that telecommunications is complementary to other forms of spatial interaction, such as trade and tourism.

Other studies have found that the attenuating effect of distance varies for different kinds of movement and at different distances. As Black (1971) and Taaffe et al. (1996) note, the distance exponent can be expected to vary with time, different modes of transportation, locational changes, different commodities, the areal extension of interaction, and different degrees of regional specialization.

Numerous researchers have also noted a systematic decrease in the friction of distance for more central locations and the tendency for steeper distance decay functions to be found in less accessible areas (Gordon, 1985; Sheppard, 1984). Gordon (1985) states that the spatial distribution of population and opportunities for interaction give rise to variations between regions in distance decay. He asserts that real income differences, scale economies, transport costs and the spatial concentration of specialized functions (the basis of hierarchies in central place theory) produce stronger distance decay effects in peripheral locations.

Other researchers have argued that the substantial variation in distance decay parameters is the result of model misspecification, specifically its failure to adequately consider spatial structure (Haynes and Fotheringham, 1984). In addition to recalibrating the model to consider the effect of competing destinations, intervening opportunities and potential models have been suggested as means of accounting for spatial structure. However, compelling evidence has been presented that the model is not necessarily misspecified and that including measures of spatial structure does not necessarily improve estimates of interaction (Desta and Pigozzi, 1991). Notwithstanding the potential for model misspecification, Haggett (1977) asserts that comparison of relative variations in gravity model parameter values for the same spatial configurations over time or for different commodities, would remain valid if the spatial structure remained constant.

General Family of Gravity Models

The basic gravity model has been refined to produce a general family of spatial interaction models (Wilson, 1970). In general, four different forms of the model exist: the total- constrained model, production-constrained model, attraction-constrained model, and doubly constrained model. Among other factors, the choice of a model depends on the scale of analysis, the purpose of the study and the availability of data. The doubly-constrained model is the most data intensive; it also produces the most accurate predictions of spatial interaction. Production and attraction-constrained models require less data and are somewhat less accurate; the total constrained-model only requires information on the total volume of interactions in a system, but produces the least reliable estimates of interaction.

Total-Constrained Model

The total-constrained gravity model is used to estimate the interaction between pairs of zones or regions when only the total volume of interaction is known. The only model constraint is that the total volume of estimated interaction between regions equal the overall amount of interaction. In order to fulfill this constraint, a balancing factor, or scalar, is included in the model (Haynes and Fotheringham, 1984; Senior, 1979).

Production-Constrained Model

In the production-constrained gravity model, information is available on the volume of movement from each origin in the spatial system. Obviously, the total number of interactions in the system is known as well. The production constrained model is useful in forecasting the total volume of interaction arriving at each destination. In addition, this form is frequently used to calibrate origin-specific gravity models to reflect the relative accessibility of origins and the perception of destination attractiveness and distance as the determinants of interaction. A balancing factor is also incorporated to insure that the total of predicted interactions originating in a given location equals the number of actual interactions originating there (Haynes and Fotheringham, 1984; Senior, 1979).

Attraction-Constrained Gravity Model

The attraction-constrained gravity model is structurally similar to the production-constrained model. If the total volume of interaction attracted to a system of locations is known beforehand, the attraction-constrained model predicts the distribution of movement from origins to destinations. The model is frequently employed in the format of a destination-specific gravity model to assess relative differences in the accessibility of a set of places that attract interaction. The model is also constrained by a balancing factor so that the total estimated interaction attracted to a specific place is equal to the actual volume of movement (Haynes and Fotheringham, 1984; Senior, 1979).

Doubly-Constrained Model

In the doubly-constrained gravity model, data are available on the total amount of interaction leaving each origin and arriving at each destination. Actual interaction between given pairs of origins and destinations, however, is not known and must be estimated. In this case, constraints on origin and destination totals operate simultaneously and interaction between a given pair of locations must be calculated iteratively (Haynes and Fotheringham, 1984; Senior, 1979).

Interpretation of Model

Distance decay functions are generally highly skewed, with a large number of flows or contacts at short distances and a substantially less interaction at greater distances. In addition, since spatial interaction is a function of the product of two masses, any plot of interaction intensity values is also likely to be skewed. Such intrinsically nonlinear relationships can be made to approximate a linear relationship through the use of the simple log transformation. Consequently, the traditional gravity model equation (1) may be transformed using the simple log transformation and interaction data can then be manipulated by linear regression (Senior, 1979; Lowe and Moryadas, 1975, Fotheringham and O'Kelly, 1989):

$$\boldsymbol{\log I_{ij} = \log a + b_1 \log P_i + b_2 \log P_j - b_3 \log d_{ij}} \qquad (5)$$

where: I_{ij}, P_i, P_j and d_{ij} are defined as above, and
a, b_1, b_2, b_3 and b_4 are estimated using linear regression

In the context of the gravity model, linear regression measures the closeness of fit between the log of actual flows and estimates of that flow. The coefficient of determination (r^2) indicates the percentage of variation in actual spatial interaction (the dependent variable) associated with variation in estimated interaction (independent variables). Regression constants and parameters provide estimates of the best weighting to apply to the negative effect of distance decay on interaction. Dummy variables and statistical measures of significant differences among regression coefficients, such as the

Chow Test, can also be applied to assess variation in the friction of distance and its change over time (Studenmund, 1992).

Though linear regression is perhaps the most commonly used form of calibrating gravity models, other methods, including the standardized root mean square error (SRMSE), have been suggested as alternatives when large error is present or interaction matrices (vectors) are highly sparse (Knudsen and Fotheringham, 1986; Desta, 1988). The SRMSE is used to calculate the most likely distance decay exponent based on actual and expected interaction values. The distance exponent is calculated iteratively, and the gravity model is recalibrated, until the SRMSE has been minimized and no further reduction in error is possible:

$$SRMSE = \left\{ \sum_i \sum_j (t_{ij} - t_{ij}^{*})^2 / (m*n) \right\}^{1/2} / \left(\sum_i \sum_j t_{ij} / m*n \right) \qquad (6)$$

where:

t_{ij} = actual flow from place i to j
t_{ij}* = predicted flow from place i to j
m = number of rows in interaction matrix
n = number of columns in interaction matrix

Use in International Trade Studies

The initial applications of the gravity model to international trade flows were carried out in the 1960s. Linnemann (1966) developed an econometrics based model to explain differences in the size of international trade flows between pairs of countries. He identified the three most obvious factors that were significant in determining the volume of trade – supply, demand and resistance. Supply and demand variables represented attractive and propulsive forces of the model and trade resisting forces fall into two categories – natural obstacles and artificial trade impediments.

Linnemann found that trade resistance varies with the type of commodity and confirmed the relevance of distance in empirical studies. He also employed a dummy variable to account for the existence of preferential trade agreements. Linnemann concluded that political and economic alliances may have led to the selective lowering of tariff barriers and import restrictions and that the effects of changes in these trade resistance factors over time, should be observable in changes in the value of the exponent of distance.

From an explicitly geographic perspective, perhaps the most significant application of the gravity model to international trade was carried out by Yeates (1969). Yeates asserted that international trade can be studied as a special form of spatial interaction that involves analysis of movements between places that are politically independent as well as physically separated. He employed a modified version of the gravity model, using total national income as an operational definition of propulsive and attractive forces and multiple regression analysis.

Like Linnemann, Yeates realized that the volume of trade between countries is affected not only by attractive and propulsive forces such as the size or purchasing power of countries, but also by political decisions reflected in multilateral and bilateral trade agreements. He stated that the importance of these political decisions can be reflected in the distance decay term.

Use in Commodity Studies

The application of the gravity model to disaggregated trade data, specifically commodity flow studies, was pioneered by Black (1971, 1972, 1974). Black (1972) explicitly examined the descriptive power of gravity model applied to flows of goods between regions – interregional commodity flows for the United States. Using a stepwise procedure to calibrate the friction of distance component of production-constrained gravity models, he discovered that the model is effective and accurate in studies where total shipments and total demand values are known for each region. On average the model accounted for 93 percent of the variation in commodity flows. Distance decay exponents, however, varied markedly, from 0.25 to 5.325.

Black emphasizes that the understanding of the variables that influence the distance exponent is poorly developed. His results reinforce general economic theory, which posits that commodity flows are influenced by the cost of overcoming distance, and the extent to which goods can bear the cost of transportation.

In a related study, Black (1971) also examined the possibility of estimating the distance exponent using variables related to variation in the friction of distance and the impact of change in the size of the study area. Using the same iterative process as above, he determined that the gravity model tends to perform better with more aggregate data and that, again, distance exponents are quite variable. He was able to identify several variables that are related to the distance exponent – number of suppliers, the type of good, and the degree of specialization. Black concluded that higher levels of specialization, implying high value and a greater proportion of shipments from largest producer, result in a lower friction of distance exponent and articulated the need to examine temporal stability of exponents.

Additional applications of the gravity model to interregional commodity flows have been carried out by Chisholm and O'Sullivan (1973), O'Sullivan and Ralston (1974), and Byler and O'Sullivan (1974).

Applying a variation of the gravity model used in the analysis of the urban transportation system, Chisholm and O'Sullivan attempted to predict interregional commodity flows in Great Britain by mode of transportation and commodity group. In addition, they employed the concept of economic potential as a surrogate measure of the potential accessibility of any one place to all other places within the system and a proxy for the facility with which the national market may be reached from each location.

Using the log-linear version of the gravity model and ordinary least-squares regression, Chisholm and O'Sullivan confirmed the hypothesis that the greater the potential accessibility of an area, the larger its volume of trade. They also confirmed that distance exponents vary considerably from one region to another; this spatial variation is interpreted as the result of an urban/rural duality. High values were characteristic of peripheral areas and low values were found in more accessible, urban areas.

In support of Black's research, Chisholm and O'Sullivan revealed significant variation in the friction of distance according to different commodity groups. They also identified a tendency for more highly valued and processed goods to have low distance decay values. Though they believe the doubly-constrained gravity model provided a reasonably good explanation of aggregate commodity flows at the national level, the performance of the model proved less than adequate in explaining disaggregated flows at the regional level. Though the variables chosen to represent propulsive and attractive forces (population and employment) were reasonably good predictors of aggregate trade, they were inadequate for predicting volumes of individual commodity groups.

Since trade flows are affected by a region's location in the space economy, Chisholm and O'Sullivan concluded that potential accessibility accounts for an acceptable proportion of the variance in distance decay values. They also emphasized the potential for research into the stability of gravity model parameters and changes over time and, though a large portion of their interaction matrix cells were empty, they restated the need to disaggregate trade flows for each regions on a commodity-specific basis.

O'Sullivan and Ralston (1974) examined the stability of parameters of model, especially the exponent applied to distance, over a four-year period. Using the Chow test to determine if significant differences existed in the coefficients of multiple regression models, their research suggested that the effect of distance should decrease over time. In noting the potential for distance decay parameters to decline over time, O'Sullivan and Ralston asserted that structural changes, such as improvements in technology and government policy, can have significant effect on the friction of distance and impact upon its stability over time.

Byler and O'Sullivan (1974) also examined explicitly the stability of gravity model parameters and the tendency for the friction of distance to decrease over time. They used multiple regression to examine changes in distance and mass terms and interpret the friction of distance coefficient as the elasticity of demand for transport with respect to distance. They concluded that a reduction in this value could be expected in conjunction with changes in transport costs due to network or vehicle improvements.

Synthesis of Literature

The geographic literature cited above indicates the potential utility of the gravity model in assessing the impact of NAFTA on US-Mexico trans-border trade. The process of economic integration, as represented by NAFTA, is clearly encompassed in the concept of spatial interaction and the general family of gravity models offers a means of assessing changes in the movement of goods.

Due the dominance of the border area and the Mexico City region, the concept of economic potential appears useful in providing an adequate measure of the attractiveness of Mexican states as destinations of US exports. The total-constrained gravity model allows for assessment of changes in overall spatial interaction. Production and attraction-constrained models (origin and destination-specific models) offer the ability to identify changes in the relative accessibility of origins and destinations.

Though the literature review identifies potential difficulties in carrying out analysis of disaggregated commodity flow data and quantifying the impact of specific barriers in impeding spatial interaction, it also substantiates the applicability of the gravity model in analyzing international trade and commodity flows. Studies provide both theoretical and empirical evidence of the role of international borders in impeding spatial interaction and the potential for decline in distance decay parameters over time and as a result of government policy. Previous research demonstrates the availability of methods to quantify spatial interaction and assess the significance of changes in interaction as a result of NAFTA.

Chapter Three

METHODS

Data Collection

Any analysis of changes in spatial interaction between the United States and Mexico since the inception of NAFTA ideally should include detailed information on the origin and destination of trade, the value and commodity classification of goods being shipped, and the mode of transportation. Such secondary data would be needed at the sub-national level, preferably at the state or county scale, in order to capture meaningful changes in spatial interaction between the two countries and possible unintended geographic consequences. In addition, data would be required over a substantial period of time, perhaps a decade or more, in order to account for economic reforms (such as Mexico's ascension to GATT) undertaken during the late 1980s. Unfortunately, such detailed trade data are not publicly available.

The Bureau of Transportation Statistics (BTS) Trans-border Surface Freight Database is the most complete source of information on trade flows between the United States and Mexico (Nozick, 1996). This data set has been available since April 1993 and is extracted from the US Bureau of Census Foreign Trade Statistics Program. Much of the trade information, approximately 55 percent of the total value of US exports and 95 percent of Mexican exports, is collected electronically at the US-Mexico border.

The BTS database is updated monthly and provides information on the movement of commodities between US and Mexican states. For US exports, the database provides detailed information on the state of origin, as well as the Mexican state of destination. Although mode data include shipments by pipeline and mail, this study will utilize data relating exclusively to movements by truck and rail, which comprise approximately 95 percent of the value of all surface exports from the United States to Mexico. Trade is grouped according to the two-digit Schedule B commodity classification, based on the international harmonized system. The database also contains details on the value and number of shipments and the Mexican border point of entry. Shipment value refers to the selling price of the merchandise plus insurance and freight costs to the US-Mexico border.

Although similar data are available for US imports from Mexico, no information is provided on the Mexican state of origin. As such, the database does not allow for analysis of changes in spatial interaction of Mexican exports. Consequently, this study will make use exclusively of US export data for the years 1993 to 1997 to assess changes in spatial interaction between the United States and Mexico following NAFTA. Interpretation of results will be limited to changes in overall and commodity-specific complementarity between the United States and Mexico, as well as changes in the accessibility of US states as sources of supply and Mexican states as sources of demand.

Data Limitations

For the purposes of this study, monthly BTS data on US exports have been aggregated into yearly totals to account for seasonal variation in the trade of certain commodities. In addition, aggregation of monthly data into annual values reduces the number of zero cell entries in the interaction matrices used to calibrate gravity models. Notwithstanding this adjustment, as much as 20 percent of the cells of overall US export matrices and more than 30 percent of some commodity and mode specific matrices are comprised of zero cell entries.

Because widespread lack of interaction may complicate model calibration, zero values have been eliminated from analysis in several recent applications of the gravity model to international trade flows (McCallum, 1995; Helliwell, 1996). However, zero cell entries are included in this study because they represent actual values that are meaningful in assessing changes in spatial interaction as a result of NAFTA. In total-constrained models calibrated using linear regression, a value of one will be added to zero cell entries in order to take the log transformation. As described above, the standardized root mean square error (SRMSE) will be employed in destination-specific gravity models to address this problem.

Though the BTS database is limited to trans-border surface trade, lack of information on trade by air and sea is not expected to impact significantly on the reliability of this study. As mentioned above, between 1993 and 1997 more than 90 percent of the value of both US exports and imports, on average, was transported by truck and rail. Due to the meager volume and value of trade via alternate modes of transportation, and for reasons of parsimony, all modes other than truck and railroad have been eliminated from this study.

The BTS database is further limited due to lack of information on commodity-specific trade flows during 1993. Data were not collected at the two-digit Schedule-B commodity classification until 1994. As a consequence, all analysis involving spatial interaction of intermediate and non-intermediate goods and liberalized and non-liberalized goods will be limited to the period 1994 to 1997.

According to Nozick (1996), the BTS database suffers from two additional problems – missing data and the number of records that list unknown origins and destinations of trade. Nozick indicates that the during its first 12 months, 5 to 10 percent of the information on trade flows was missing from the database. In addition, for the first year, 22 percent of the total value of exports was listed as other or unknown. As Nozick notes, however, the quality of the database has improved substantially since changes were made in 1994. According to BTS, the number of unknown destinations of US exports had declined to approximately 10 percent by April 1994. Although some consideration was given to the notion of allocating US exports lacking destination information to Mexican states on the basis of available information and general patterns of trade, missing data were ultimately regarded as random. Consequently, BTS database entries listed as "other" and "unknown" have been eliminated from this study.

Other major limitations of the database include lack of information on the origin of Mexican exports, the use of dollar values rather than numbers of trucks, rail cars or freight tonnage, and lack of a direct means of identifying maquiladora traffic. Although data on the Mexican state of origin are collected (though unpublished for reasons of confidentiality), none of these problems has been addressed, to date, by the Bureau of Transportation Statistics.

Data Analysis

Hanink (1994) asserts that most policies that affect and are affected by international trade flows can be viewed as uniformly distributed across the space of national states. This study, however, presupposes a different relationship between national policy and geographic and economic outcomes. The impact of the North American Free Trade Agreement will likely vary among nations, regions of individual countries and sectors of national and regional economies. Therefore, analysis of changes in spatial interaction and relative accessibility will focus on trade flows between US and Mexican states.

The movement of US exports to Mexico between 1993 and 1997 will be modeled to identify changes in spatial interaction following implementation of NAFTA. In addition to quantifying changes in the overall friction of distance between the two countries, trade flows will be modeled at the state level to reveal changes in the relative accessibility of trade origins and destinations.

Following Knudsen (1988), binary matrices will be used to assess changes in total and commodity-specific complementarity among origins and destinations between 1994 and 1997. Overall differences in complementarity for each country between 1994 and 1997 will evaluated statistically using the paired t-test.

Table 1. ***Sample Binary Matrix***

From\To	**Destination 1**	**Destination 2**	**Destination 3**	**Destination 4**	*Total*
Origin 1	1	0	1	0	2
Origin 2	1	1	1	0	3
Origin 3	1	1	1	1	4
Origin 4	1	0	0	0	1
Total	4	2	3	1	10

Use of Binary Matrices

As the above example (Table 1) indicates, a cell entry of one indicates the presence of a commodity flow between a specific origin and destination. A zero cell entry, however, indicates lack of complementarity between a given pair of places. Row totals provide a measure of complementarity for each trade origin and column sums indicate complementarity expressed as the demand exercised by individual destinations. Row and column totals may also be expressed as percentages in order to provide a relative measure of complementarity and a means of quantifying changes in supply and demand over time. For example, in the above table, the total complementarity of Origin 1 can also be expressed as 50% (2/4). Furthermore, the total number of commodity flows in the matrix (10) provides an indication of the overall level of complementarity among origins and destinations. This quantity also may be expressed as a percentage (62.5%) to facilitate interpretation or comparison.

Calibration of Gravity Models

As mentioned above, the BTS database only provides information on interaction between US and Mexican states. Consequently, interaction matrices are incomplete because no data are available on trade flows that originate and terminate within the same country (or the same state). Lack of information on flows within a given state or country may result in biased distance decay exponents as models fail to indicate how rapidly interaction falls off with distance from the origin.

Likewise, as illustrated by the relative locations of Texas and Maine, a potential bias may exist in the distance matrix. In no case does Texas interact with Mexican states at a distance greater than 2100 miles. However, Maine interacts with no Mexican state at a distance less than 2500 miles. In conjunction with incomplete interaction matrices, the systematic differences in distances could result in biased distance decay exponents.

In order to compensate for these potential limitations, data from the 1993 US Commodity Flow Survey (CFS) will be used to supplement gravity model interaction matrices. Since the CFS only provides data on interstate and intrastate trade for US origins, only origin-specific gravity models can be calibrated in this thesis. As a result, analysis of changes in relative accessibility will be limited to US states that generate commodity flows to Mexican states. Although CFS data do not exist for 1997, likely interstate and intrastate trade values can be predicted using gross state product (GSP) as the independent variable in a simple linear regression model. Linear regression indicates that GSP for 1993 explains 86 percent of variation in 1993 commodity flows. By using coefficients from the 1993 regression model and GSP values for 1997, fairly reliable estimates of 1997 commodity flows can be obtained and used to calibrate origin-specific gravity models.

BTS trade data for 1993, supplemented by the 1993 CFS, will serve to calibrate production-constrained gravity models for a base year, representing the overall level of spatial interaction, degree of distance deterrence, and relative accessibility of origins prior to the commencement of NAFTA. Due to the lack of commodity-specific data for 1993, commodity specific models will be calibrated for 1994 and 1997. Changes in the relative accessibility of places that generate trade, as well as the friction of distance will be calculated for each year. Distance decay parameters for 1994 and 1997 will be analyzed statistically to determine if significant changes have occurred following implementation of NAFTA.

As Figure 1 shows, US and Mexican highway systems were used to determine the distances between US and Mexican states. In the case of the United States, the exact geographic centroid of each state was located. The actual point used for the calculation of distance was determined by adjusting the position of the centroid to the nearest urban area on the Interstate Highway System. Centroids of Mexican states were determined by identifying the dominant urban area in each state, in addition to Mexico City. In all instances, these urban areas were connected to the Mexican Federal Highway system. After locating geographic centroids, the US-Mexico distance matrix used to calibrate gravity models was obtained.

Two distinct forms of gravity models are proposed in this study. The total-constrained gravity model will be used to examine changes in overall friction of distance between the United States and Mexico as a result of NAFTA. The production-constrained (origin-specific) model will be used to explore changes in the relative accessibility of places that generate trade (US states).

Total-constrained models will be calibrated on the basis of total value of trade and for different modes (rail and truck) and commodity groups (intermediate goods, liberalized products, etc.). Though true attraction-constrained (destination-specific) gravity models cannot be calibrated in this thesis, intercept and slope dummy variables will be included in total-constrained models to determine if Mexican border states, as centers of demand, experience a different level of distance deterrence than non-border states.

Figure 1. US and Mexican Highway Systems

For the purposes of the total-constrained model, the overall value of exports to Mexico will be used to represent the propulsiveness of US states (supply) and the total value of imports from the United States will describe the attractiveness of Mexican states (demand). As mentioned above, multiple regression analysis will be used to calibrate total-constrained models for 1993 and 1997. The Chow Test will be used to determine if coefficients of the gravity model differ significantly over time (Studenmund, 1992):

$$CHOW = \frac{(RSS_t - RSS_1 - RSS_2)/k+1}{(RSS_1 + RSS_2)/(n_T - 2k - 2)} \tag{7}$$

where:

RSS_T = Residual sum of squares of pooled model
RSS_1 = Residual sum of squares of model one
RSS_2 = Residual sum of squares of model two
k = number of independent variables
n_T = number of observations in the pooled model

Origin-specific gravity models will be calibrated using the standardized root mean square error (SRMSE). As mentioned above, these models will be used to assess changes in the distance decay functions for different origins between 1993 and 1997. In order to assess the statistical significance of changes in distance decay exponents of models calibrated using the SRMSE, the paired form of the t-test will be employed.

Chapter Four

RESULTS

The primary hypothesis of this thesis is that implementation of the North American Free Trade Agreement in 1994 has brought about significant changes in spatial interaction between the United States and Mexico. This hypothesis will be tested by examining patterns of change in complementarity (supply and demand) and transferability (friction of distance) from 1993 to 1997. Changes in spatial interaction will be assessed for total trade, trade in different commodity groups and different modes of transportation.

Complementarity

Total complementarity refers to the overall level of spatial interaction among a set of origins and destinations. Origin-specific complementarity reflects a given state's attractiveness as a source of raw materials, intermediate goods and finished products, as well its overall level of interaction with Mexican states. Destination-specific complementarity represents a state's level of demand of raw materials, intermediate goods and finished products, as well as its overall level of interaction with US states.

In the context of this study, total complementarity is calculated as the sum of interactions for a specific origin or destination in each of ten commodity groups. In order to facilitate comparison of total complementarity and changes in interaction between 1993 and 1997, values have been converted to percentages.

Complementarity by State

As Tables 2 and 3 indicate, total complementarity between the United States and Mexico increased between 1994 and 1997. Paired t-tests reveal that increases in total complementarity are statistically significant for both the United States (5.512) and Mexico (2.454), signifying significant changes in both sources of supply and demand between 1994 and 1997. As a consequence, *Hypothesis One*, regarding significance of changes in total complementarity, is rejected.

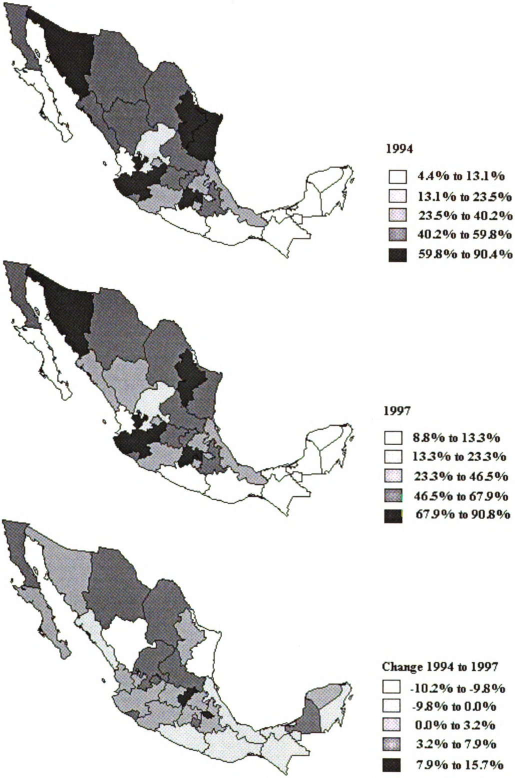
As displayed in Figure 2, the highest levels of total complementarity among Mexican states are found along in the border area, the Mexico City region, and the state of Jalisco. Not surprisingly, the lowest levels of complementarity are found in southern Mexico, the Yucatan Peninsula, and the state of Baja California Sur.

Increases in overall demand among Mexican states is concentrated in the northern part of the country. However, substantial growth in demand can also be found among smaller, more distant states (Tlaxcala, Morelos, Nayarit, and Campeche), as well as central border states. Though reduced complementarity is relatively infrequent, substantial decreases in demand are located in Durango and the border state of Tamaulipas.

Table 2. *Total Complementarity, Mexico 1994-1997*

MEXICO	1994	1997	Change
Aguascalientes	39.40%	46.50%	7.10%
Baja California Norte	48.50%	55.60%	7.10%
Baja California Sur	11.70%	13.30%	1.60%
Chihuahua	59.80%	65.00%	5.20%
Colima	49.20%	54.20%	5.00%
Campeche	4.40%	12.30%	7.90%
Coahuila	59.80%	64.80%	5.00%
Chiapas	9.40%	8.80%	-0.60%
Distrito Federal	90.40%	90.80%	0.40%
Durango	51.70%	41.90%	-9.80%
Guerrero	13.10%	13.10%	0.00%
Guanajuato	58.50%	60.40%	1.90%
Hidalgo	35.20%	36.70%	1.50%
Jalisco	73.10%	76.30%	3.20%
Michoacan	35.20%	38.10%	2.90%
Morelos	40.20%	44.20%	4.00%
Mexico	81.30%	83.10%	1.80%
Nayarit	9.80%	11.30%	1.50%
Nuevo Leon	81.50%	83.30%	1.80%
Oaxaca	12.50%	10.00%	-2.50%
Puebla	50.80%	53.50%	2.70%
Quitana Roo	13.10%	10.00%	-3.10%
Queretaro	53.10%	67.90%	14.80%
Sinaloa	46.30%	43.80%	-2.50%
San Luis Potosi	49.20%	55.40%	6.20%
Sonora	70.20%	73.30%	3.10%
Tabasco	11.50%	9.60%	-1.90%
Tlaxcala	23.50%	39.20%	15.70%
Tamaulipas	67.30%	57.10%	-10.20%
Veracruz	37.30%	36.70%	-0.60%
Yucatan	8.50%	9.20%	0.70%
Zacatecas	19.00%	23.30%	4.30%
AVERAGE	41.10%	43.40%	2.32%
T-test 1994-1997	t=2.454*		

Figure 2. Total Complementarity, Mexico -- 1994-97



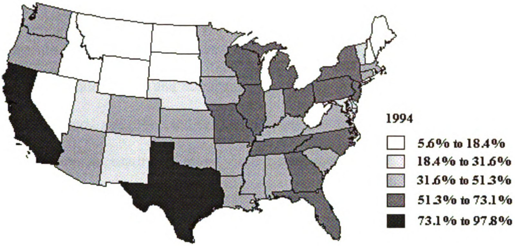
Among US states, Texas and California clearly display the greatest levels of complementarity (Figure 3). With the exception of these border states, however, the highest levels of complementarity, almost uniformly, are located east of the Mississippi River, especially in the traditional US manufacturing belt and the Southeast. The states least likely to supply goods to Mexico are both relatively distant from the border and have fairly small economies. Two regions of little complementarity, in particular, are evident in the Upper Great Plains and New England.

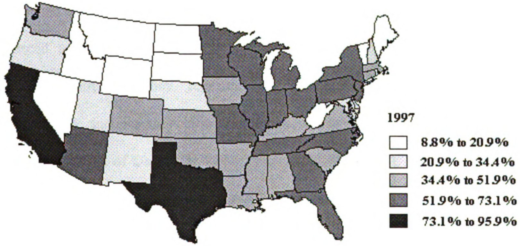
Like their Mexican neighbors, US states also display widespread increases in complementarity between 1994 and 1997. Although the most dramatic increases in interaction are scattered across several areas of the country, a general trend towards increased complementarity can be found in areas with historically less interaction (Upper Great Plains and Far West). Substantial gains are also noted in the Great Lakes states and the southern part of the country. Decreases in complementarity are localized and small, but include the states of Texas, Florida, Oregon, North Dakota, Missouri, Kentucky and Maryland.

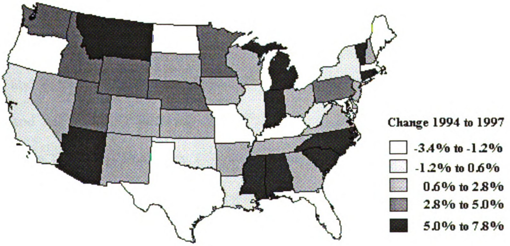
Table 3. ***Total Complementarity, United States 1994-1997***

US	1994	1997	Change
Alabama	40.90%	46.90%	6.00%
Arkansas	40.00%	41.90%	1.90%
Arizona	50.60%	56.60%	6.00%
California	90.00%	90.30%	0.30%
Colorado	41.60%	44.10%	2.50%
Connecticut	44.10%	51.90%	7.80%
Delaware	22.80%	24.40%	1.60%
Florida	63.40%	61.90%	-1.50%
Georgia	59.40%	60.90%	1.50%
Iowa	41.60%	43.10%	1.50%
Idaho	17.20%	20.90%	3.70%
Illinois	73.10%	73.10%	0.00%
Indiana	47.50%	54.70%	7.20%
Kansas	42.20%	45.00%	2.80%
Kentucky	41.30%	38.80%	-2.50%
Louisiana	45.90%	46.30%	0.40%
Massachusetts	48.10%	46.60%	-1.50%
Maryland	31.60%	29.70%	-1.90%
Maine	14.10%	12.20%	-1.90%
Michigan	59.10%	64.70%	5.60%
Minnesota	51.30%	55.30%	4.00%
Missouri	61.90%	60.00%	-1.90%
Mississippi	35.60%	41.60%	6.00%
Montana	5.90%	12.50%	6.60%
North Carolina	52.80%	58.10%	5.30%
North Dakota	10.00%	8.80%	-1.20%
Nebraska	30.30%	34.40%	4.10%
New Hampshire	21.30%	24.10%	2.80%
New Jersey	58.80%	60.60%	1.80%
New Mexico	26.30%	27.50%	1.20%
Nevada	18.40%	20.30%	1.90%
New York	62.50%	63.10%	0.60%
Ohio	60.60%	63.10%	2.50%
Oklahoma	43.40%	43.40%	0.00%
Oregon	35.90%	32.50%	-3.40%
Pennsylvania	59.40%	64.40%	5.00%
Rhode Island	16.30%	22.50%	6.20%
South Carolina	37.80%	44.10%	6.30%
South Dakota	15.30%	16.60%	1.30%
Tennessee	57.20%	60.00%	2.80%
Texas	97.80%	95.90%	-1.90%
Utah	27.80%	31.90%	4.10%
Virginia	43.40%	45.90%	2.50%
Vermont	11.30%	16.60%	5.30%
Washington	40.60%	44.70%	4.10%
Wisconsin	55.90%	58.10%	2.20%
West Virginia	13.80%	13.40%	-0.40%
Wyoming	5.60%	9.70%	4.10%
AVERAGE	41.10%	43.40%	2.32%
T-test 1994-1997	t=5.512*		

Figure 3. Total Complementarity, United States -- 1994-97







Complementarity by Commodity Group

Although border states are the dominant sources of supply and demand in both countries, analysis of commodity-specific complementarity and changes in complementarity, can be useful in illustrating varying levels of specialization in different regions of the United States and Mexico. In general, the lowest levels of complementarity exist in agricultural and processed food commodity groups. Not surprisingly, the greatest degree of complementarity is found in the machinery commodity group, which is comprised largely of intermediate goods (Figure 4).

As shown in Figure 4, two trends are apparent in complementarity between the United States and Mexico for the period 1994 to 1997. Seven of ten commodity groups experienced a decline in complementarity in 1995. Though these changes are not statistically significant, they represent an exception to the trend of greater complementarity and are the obvious outcome of the Mexican economic crisis and currency devaluation of December 1994. Three commodity groups, Food and Processed Agricultural Products, Paper Products, and Textiles and Apparel, displayed increases in complementarity in 1995 in spite of the economic downturn in Mexico.

Nine of ten commodity groups also experienced overall increases in complementarity between 1994 and 1997. The only exception to this trend occurred in Food and Processed Agricultural Products, which experienced peak complementarity in 1995 and has generally declined since. Table 4 reveals the statistical significance of changes in the complementarity of specific commodity groups. In five of ten cases, *Hypothesis Two* is rejected for Mexican states. In the case of the United States, *Hypothesis Two* is rejected in six of ten instances.

Figure 4. Changes in US-Mexico Complementarity, 1994-1997

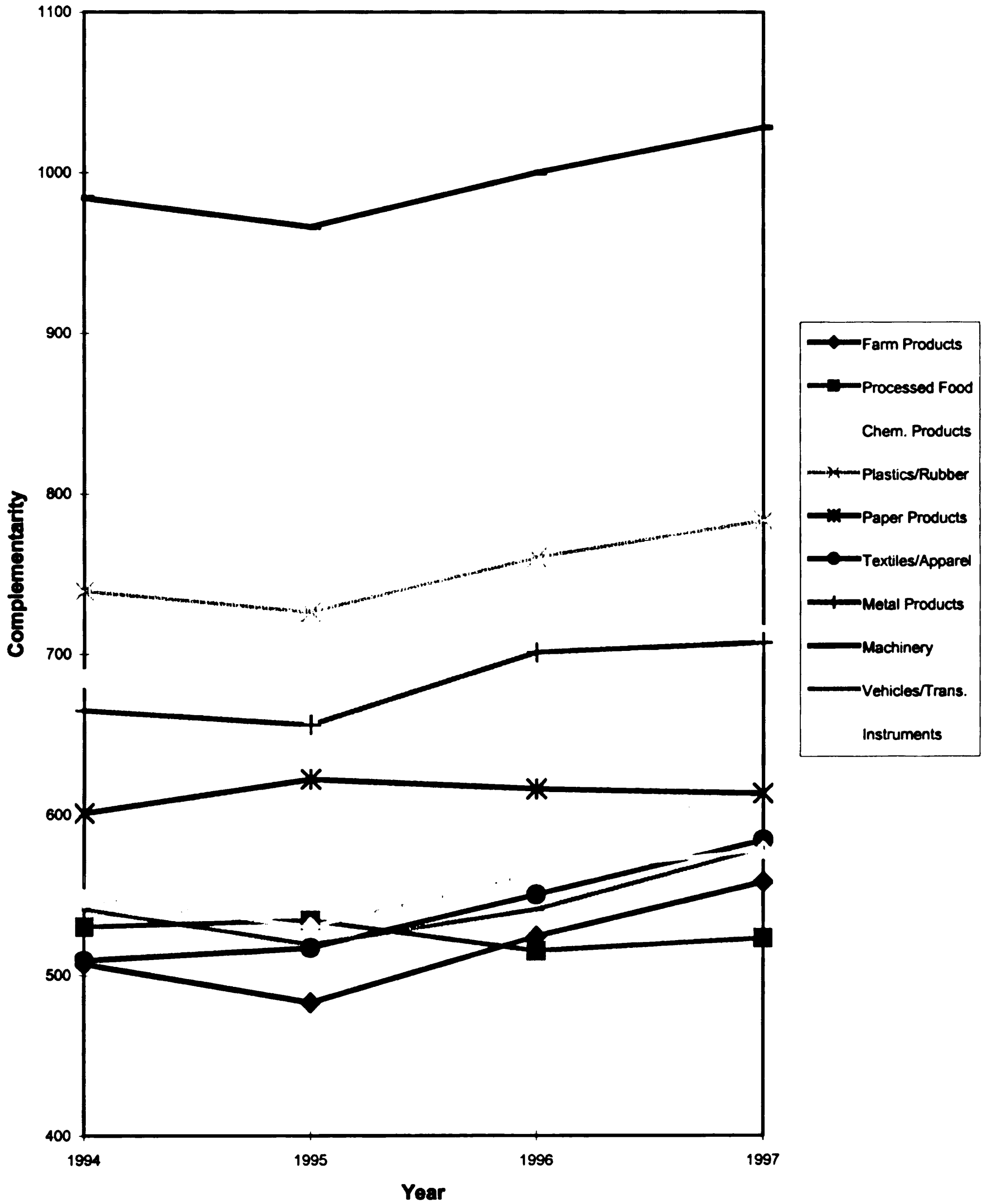


Table 4. ***Changes in Complementarity by Commodity Group, 1994-1997***

Commodity Group	Complementarity 1994	Complementarity 1997	T-Statistic Mexico	T-Statistic United States
Agricultural Products	33.0%	36.3%	2.38*	2.11*
Food/Processed Ag. Products	34.5%	33.5%	-0.29	-0.33
Chemical Products	44.6%	46.4%	1.2	1.41
Rubber and Plastic Products	48.1%	51.0%	2.18*	2.57*
Paper Products	39.1%	39.9%	0.50	0.69
Textiles and Apparel	33.1%	38.0%	3.12*	4.12*
Metal Products	43.3%	46.0%	1.94*	2.58*
Machinery	64.0%	66.9%	1.84*	2.60*
Transportation	35.2%	37.7%	1.68	2.39*
Instruments	35.7%	37.6%	1.33	1.61

Agricultural Products

As Figure 5 reveals, the greatest levels of demand for agricultural products in Mexico are found along the border and in the Mexico City region. The lowest levels of demand are concentrated in the southern part of the country. Though Texas and California represent the dominant supply areas within the United States, the role of the Midwest in supplying agricultural products is readily apparent (Figure 6).

Paired t-tests reveal that statistically significant increases occurred in the complementarity of agricultural products for both the United States and Mexico between 1994 and 1997 (Table 4). In Mexico, the most prominent increases are concentrated in the border area though some growth in demand is also found in the southern states of Chiapas and Yucatan. The greatest change in the supply of agricultural products, however, is the trend towards decreased complementarity among states in the western third of the United States. Increased complementarity is most likely to be found in the eastern half of the country.

Figure 5. Complementarity in Agricultural Products, Mexico -- 1994-97

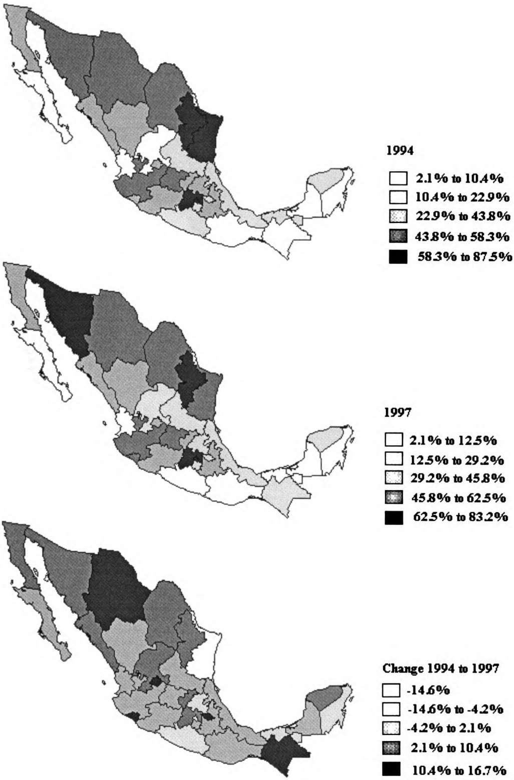
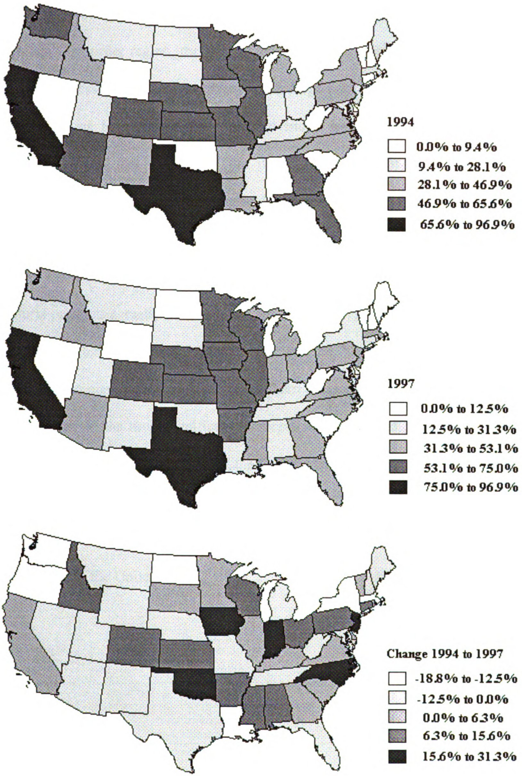


Figure 6. Complementarity in Agricultural Products, US -- 1994-97



Food and Processed Agricultural Products

In Mexico, the dominant sources of demand for food and processed agricultural products are the border region, the state of Jalisco and the Mexico City area (Figure 7). Demand of processed food products is relatively large north of Mexico City; states south of the Valley of Mexico generally display much less complementarity. With the exception of Texas and California, the dominant sources of supply of processed agricultural products, like the prior agricultural commodity group, are found in the Midwest (Figure 8).

As mentioned above, the degree of complementarity of food and processed agricultural products actually declined between 1994 and 1997. However, some increases in demand can be found in the border area and the Yucatan Peninsula. In general, however, the complementarity of states in southern Mexico decreased following 1994. As shown in Figure 8, the most significant increases in supply among US states following the inception of NAFTA are located in the Upper Midwest and the Upper Great Plains. Moderate growth is also found in the Northeast and parts of the South. Decreasing complementarity is most prominent among states in the Southwest and along the southeast coast of the United States.

Figure 7. Complementarity in Food and Processed Ag. Products, Mexico -- 1994-97

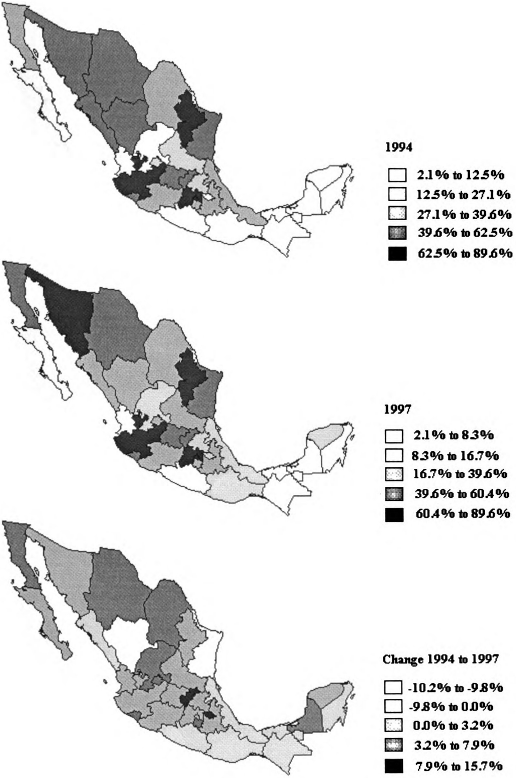
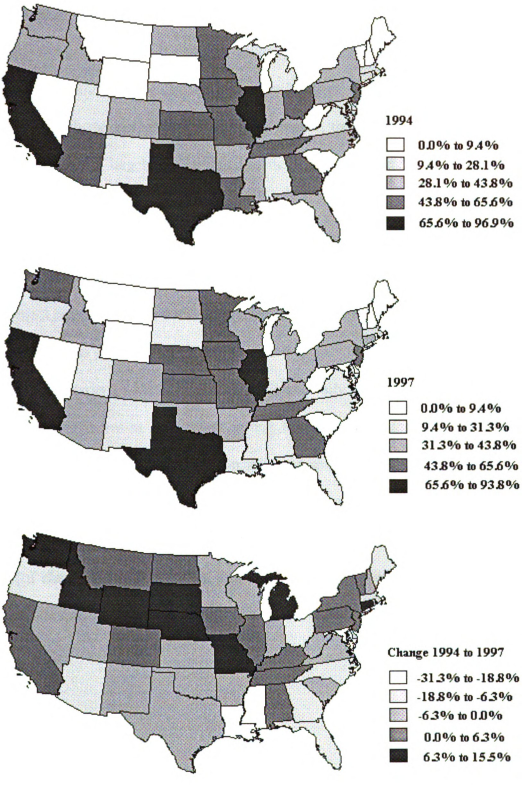


Figure 8. Complementarity in Food and Processed Ag. Products, US -- 1994-97



Chemical Products

A high level of demand for chemical products is found in northern Mexico, extending from the border to the Mexico City region. In general, southern Mexico and the state of Baja California Sur display the lowest levels of demand for chemical products (Figure 9). With the exception of the border region, the supply of chemical products among US states is largely concentrated in the traditional manufacturing belt and the eastern half of the country (Figure 10).

Though moderate increases are apparent in the complementarity of chemical products between 1994 and 1997, statistical tests do not reveal significant changes for either the United States or Mexico. Binary matrices reveal that complementarity of chemical products peaked in 1996 and decreased slightly in 1997. As Figure 9 indicates, the complementarity of Mexican border states generally declined following 1994. The most prominent increases in demand among Mexican states are found among states bordering the Gulf of Mexico and in a part of northern Mexico between the border and Mexico City. States along Mexico's Pacific coast, however, generally exhibited stagnant or declining levels of complementarity. In the case of the United States, increases in the supply of chemical products can be found throughout the country, though a pattern of increased complementarity is most prominent west of the Mississippi River.

Figure 9. Complementarity in Chemical Products, Mexico -- 1994-97

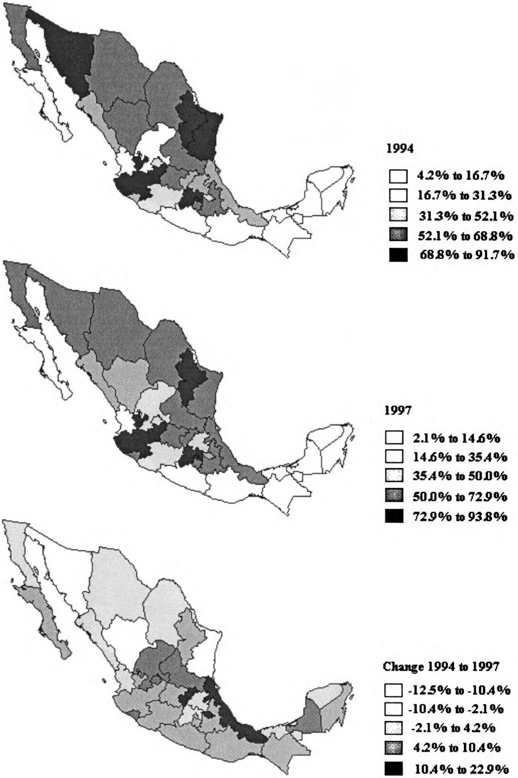
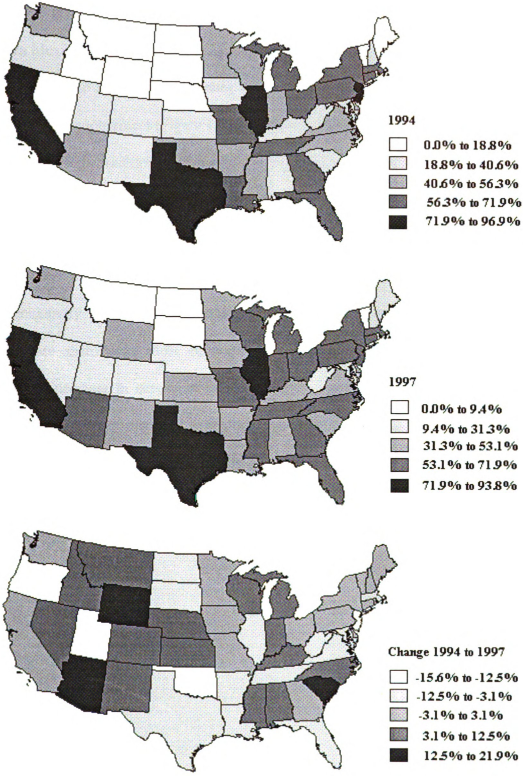


Figure 10. Complementarity in Chemical Products, US -- 1994-97

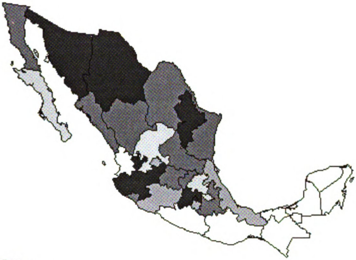


Rubber and Plastic Products

The greatest levels of demand for rubber and plastic products is concentrated in northern Mexico, from the border to Mexico City. Again, the lowest levels of demand are concentrated in southern Mexican states with relatively low incomes and lower levels of manufacturing employment (Figure 11). Supply of this commodity group is most strongly associated with the traditional US manufacturing core, as well as the Southeast. States in the Great Plains and West, with the exception of California, are much less likely to supply rubber and plastic products to Mexican states (Figure 12).

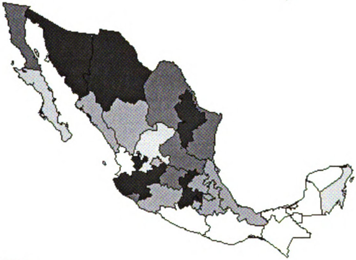
Both countries underwent statistically significant increases in the complementarity of rubber and plastic products between 1994 and 1997. Increases in demand are distributed most prominently throughout central Mexico. The most impressive increases in supply of this commodity group are scattered throughout the United States, though increased complementarity is noted in the southern part of the country. Relatively little change in supply is found in the northeastern part of the country, as well as the western part of the country (Figure 12).

Figure 11. Complementarity in Rubber/Plastic Products, Mexico -- 1994-97



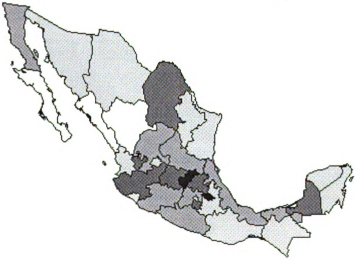
1994

- 2.1% to 18.8%
- 18.8% to 35.4%
- 35.4% to 52.1%
- 52.1% to 72.9%
- 72.9% to 91.7%



1997

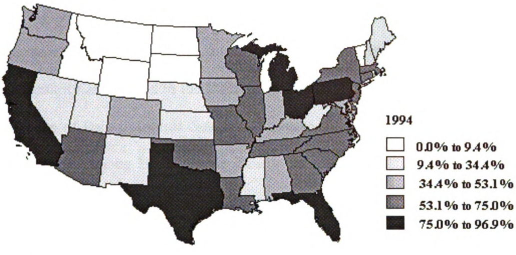
- 8.3% to 14.6%
- 14.6% to 27.1%
- 27.1% to 58.3%
- 58.3% to 75.0%
- 75.0% to 91.7%

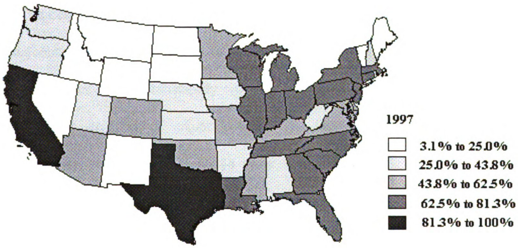


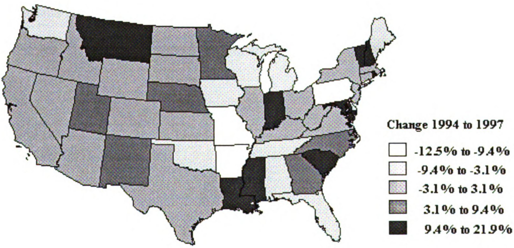
Change 1994 to 1997

- -10.4% to -6.3%
- -6.3% to 0.0%
- 0.0% to 6.3%
- 6.3% to 14.6%
- 14.6% to 22.9%

Figure 12. Complementarity in Rubber/Plastic Products, US -- 1994-97







Paper Products

As Figure 13 reveals, high levels of demand for paper products are located in the border region and the Mexico City area. States displaying significantly lower levels of complementarity are located in the Yucatan Peninsula, the southern part of the country and the state of Baja California Sur. In addition to Texas and California, the greatest levels of supply among US states are clearly concentrated in the eastern half of the country. US states least likely to supply paper are located in the Great Plains and western part of the country (Figure 14).

The complementarity of paper products peaked in 1995 and has declined slightly in subsequent years. Though overall complementarity increased somewhat between 1994 and 1997, changes are not statistically significant. Consequently, the most salient pattern in supply and demand of paper products is the generally stagnant levels of complementarity. As Figures 13 and 14 show, a moderate decease in complementarity can be found in the border regions of both countries, as well as the northwestern part of the United States. Increases in demand among Mexican states are found in Jalisco and along Mexico's Pacific coast. Relatively few increases in supply are apparent among US states. States displaying the most prominent increases include Michigan, Nevada and Tennessee.

Figure 13. Complementarity in Paper Products, Mexico -- 1994-97

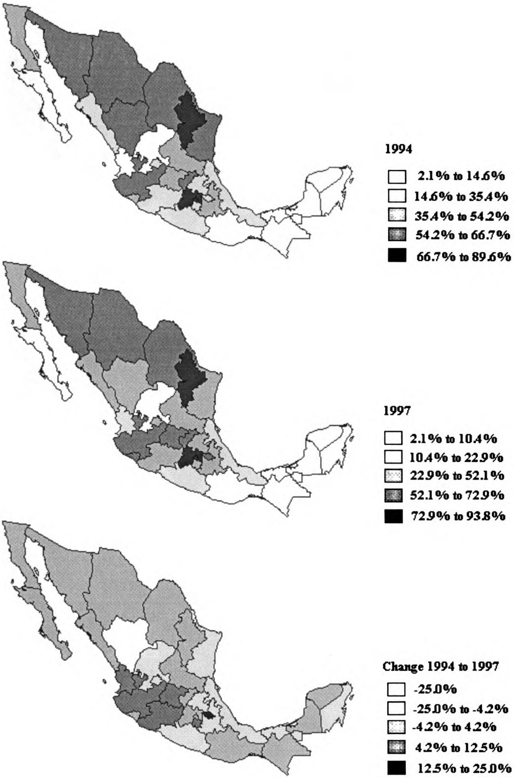
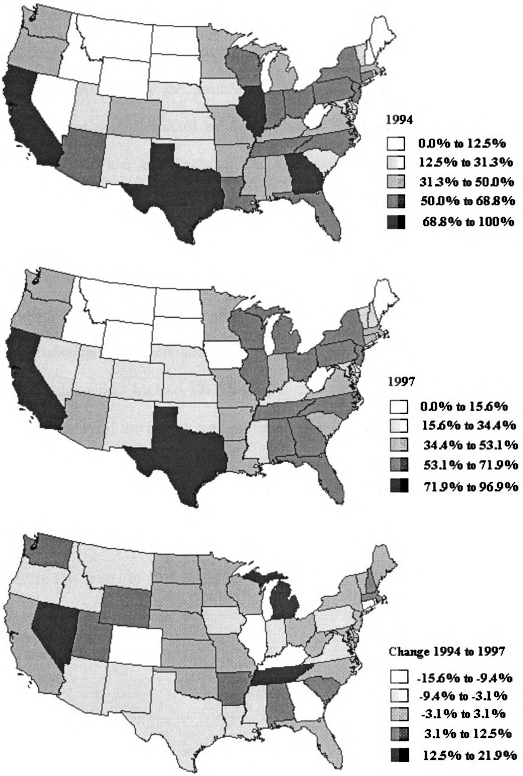


Figure 14. Complementarity in Paper Products, US -- 1994-97



Textiles and Apparel

Not surprisingly, the greatest levels of demand for textiles and apparel are found along the border and in the Mexico City region. The lowest levels of demand are concentrated in southern and southeastern Mexico (Figure 15). The supply of this commodity group is dominated by the US border states and the eastern part of the country, in particular the Southeast and Northeast. In general, states west of the Mississippi River (Upper Great Plains and Far West) have relatively little interaction with Mexican states in this commodity group (Figure 16).

The most notable changes in US-Mexico complementarity between 1994 and 1997 are found in this commodity group. Paired t-tests reveal highly significant increases in complementarity for both countries. Though increasing demand is distributed fairly uniformly throughout Mexico, the most significant change is a dramatic decrease in the complementarity of the border state of Tamaulipas. Among US states, increases in the supply of textiles and apparel are most apparent in the Southeast and the manufacturing core. The US border region, in general, exhibits a slight decline in levels of complementarity between 1994 and 1997. In addition, though the Far West displays relatively low levels of complementarity in this commodity group, these states tend to exhibit either relatively little change in complementarity or moderate decreases between 1994 and 1997.

Figure 15. Complementarity in Textiles and Apparel, Mexico -- 1994-97

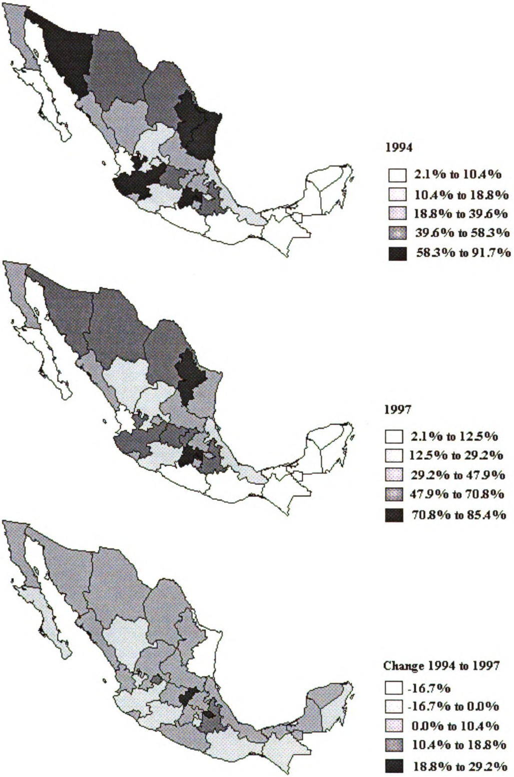
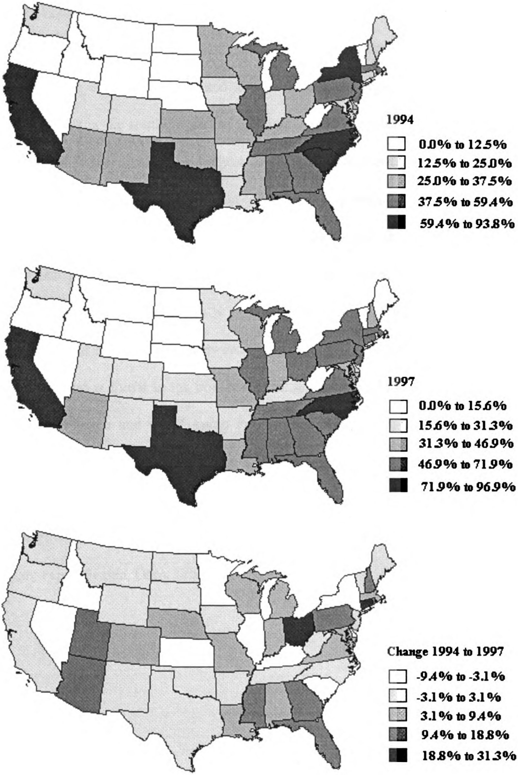


Figure 16. Complementarity in Textiles and Apparel, US -- 1994-97



Metal Products

As Figure 17 reveals, states north of Mexico City generally display high levels of demand for metal products. Again, the greatest levels of demand are concentrated in the border area, the state of Jalisco and the Mexico City region. Complementarity is considerably less in the southern part of the country and the Yucatan Peninsula. Though Texas and California display the highest levels of complementarity among US states, Figure 18 clearly shows the concentration of supply (and production) of metal products in the traditional manufacturing core of the United States and the Southeast. Levels of complementarity are substantially less in the Great Plains and Far West.

Paired t-tests reveal statistically significant increases in the supply and demand of metal products for both countries between 1994 and 1997. In the case of Mexico, though increased demand is found in the border region, greater complementarity also occurs in south-central Mexico and the Yucatan Peninsula. Furthermore, though California and Texas exhibit moderate decreases in the supply of metal products, the most prominent growth is found in the Great Plains and the West. Figure 18, however, also reveals moderate growth among several states in the traditional manufacturing core (New York, Michigan, Pennsylvania, Ohio, Illinois).

Figure 17. Complementarity in Metal Products, Mexico -- 1994-97

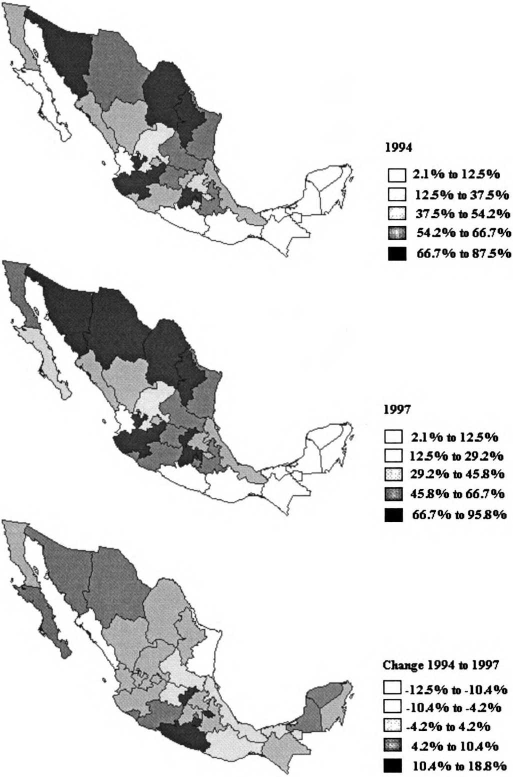
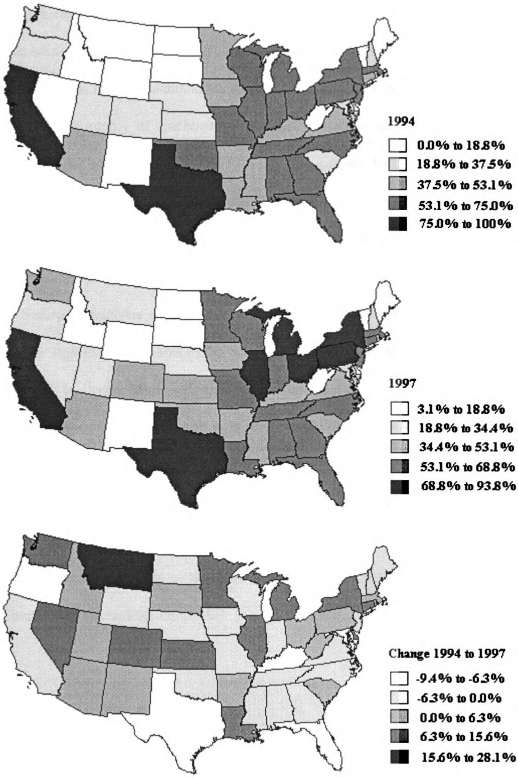


Figure 18. Complementarity in Metal Products, US -- 1994-97



Machinery

Mexican demand for machinery is concentrated in northern Mexico, extending from the border to the state of Jalisco and the Mexico City area. As with most commodity groups, the lowest levels of demand are located in the southern part of the country (Figure 19). Though the supply of machinery is greatest in California and Texas, the greatest concentration of complementarity is found in the eastern half of the United States. Although most US states display relatively high levels of complementarity in this commodity group, states in the Upper Great Plains generally exhibit lower levels of supply (Figure 20).

Statistical analysis reveals that both Mexico and the United States experienced statistically significant increases in the complementarity of machinery between 1994 and 1997. Due to very high existing levels of spatial interaction, however, the complementarity of core regions in both counties failed to undergo significant growth. The greatest increases in Mexican demand were found in non-border states in the northern part of the country and Campeche, in the Yucatan Peninsula. Though the most substantial increases in supply among US states are concentrated in the Far West and the Deep South, to a lesser degree, the most prominent change in complementarity is the clear pattern of decreasing interaction among states in the Midwest and Upper Great Plains.

Figure 19. Complementarity in Machinery, Mexico -- 1994-97

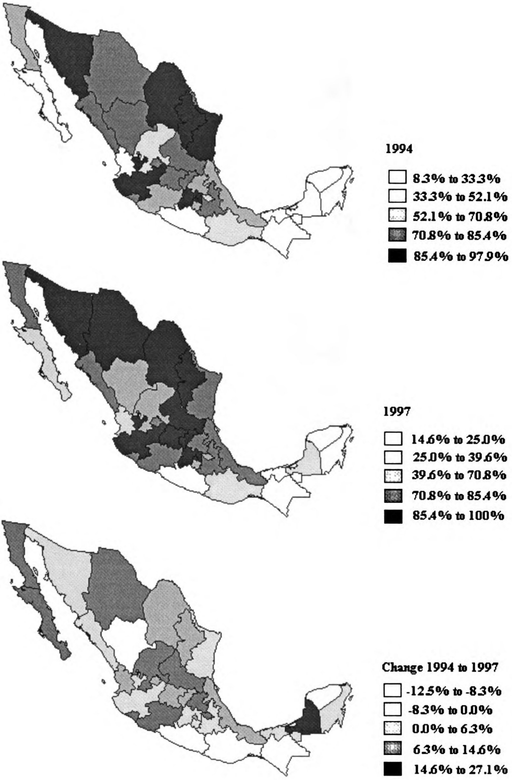
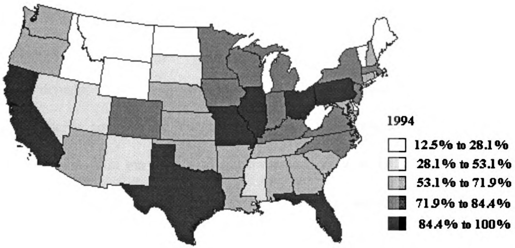
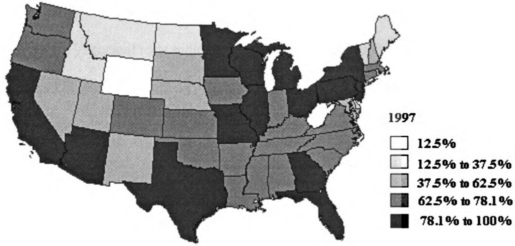
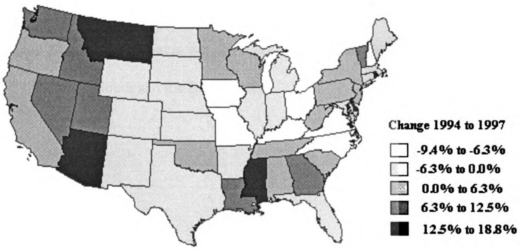


Figure 20. Complementarity in Machinery, US -- 1994-97







Transportation Products

In general, border states, the Mexico City area and the state of Jalisco represent the dominant centers of demand for vehicles and transportation products. As Figure 21 indicates, demand is relatively low among states in southern Mexico, from Guerrero along the Pacific coast to the Yucatan Peninsula. In addition to Texas and California, Figure 22 reveals that the supply of transportation products is clearly centered on the traditional US manufacturing core, the Great Lakes and parts of the Midwest. With the exception of border states, the western part of the country displays relatively little complementarity in this commodity group.

Though statistical tests indicate significant changes in the supply of transportation products for US states between 1994 and 1997, increases in the demand for transportation products among Mexican states are not significant. This result is not surprising since this commodity group largely represents intermediate goods that originate in a number of US states destined for assembly in Mexican border states and eventual re-export. With the exception of the state of Campeche in the Yucatan Peninsula, the greatest increases in demand are found along the border and in the northern part of the country. In the case of the United States, supply increases are fairly widespread, including the Upper Great Plains, parts of the South and the East Coast.

Figure 21. Complementarity in Transportation Products, Mexico -- 1994-97

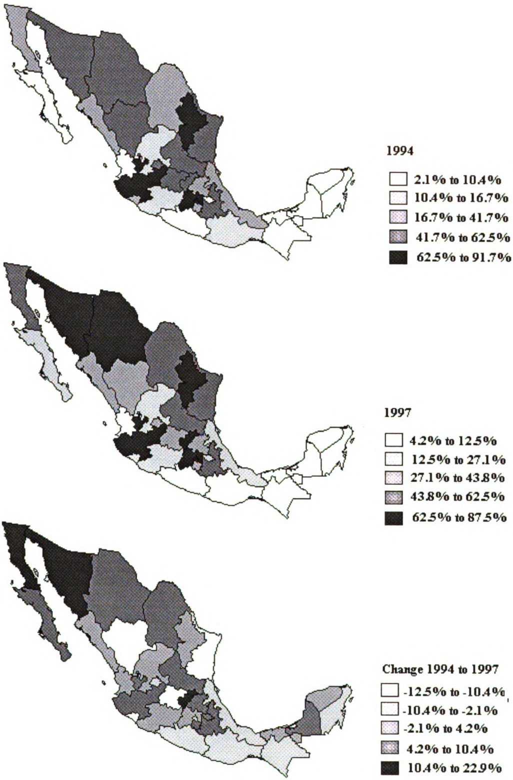
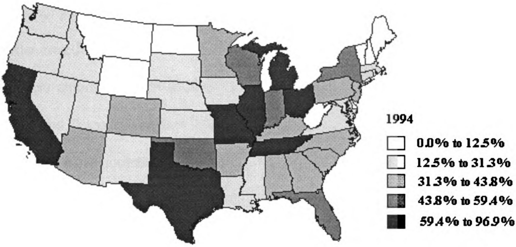
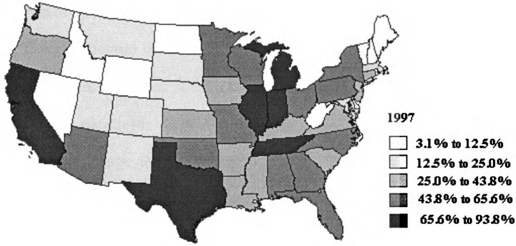
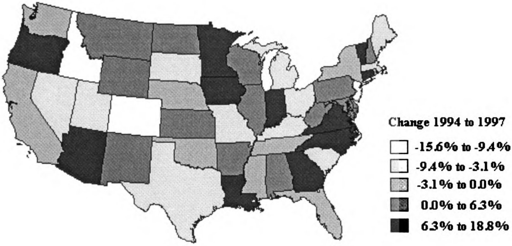


Figure 22. Complementarity in Transportation Products, US -- 1994-97







Instruments

Among Mexican states, the greatest levels of demand for instruments are found in the border area, Jalisco and Mexico City (Figure 23). Very low levels of complementarity are apparent among states in southern and southeastern Mexico. With the exception of California and Texas, the highest levels of complementarity in this commodity group are concentrated in the northeastern quarter of the country, including the Great Lakes states and parts of the East and Midwest. Though the South displays relatively little complementarity, the lowest levels of supply are found in the Upper Great Plains and the western part of the United States (Figure 24).

Though moderate increases in the complementarity of instruments are apparent for both the United States and Mexico between 1994 and 1997, paired t-tests reveal that changes are not statistically significant. The most prominent changes in demand among Mexican states are large decreases along Pacific and Atlantic coats, as well as moderate increases in the center of the country and in the border states of Chihuahua and Coahuila. Among US states, fairly large decreases are found in the West and the Upper Great Plains. Moderate increases are identified in the Great Plains and the South, as well as parts of the Northeast.

Figure 23. Complementarity in Instruments, Mexico -- 1994-97

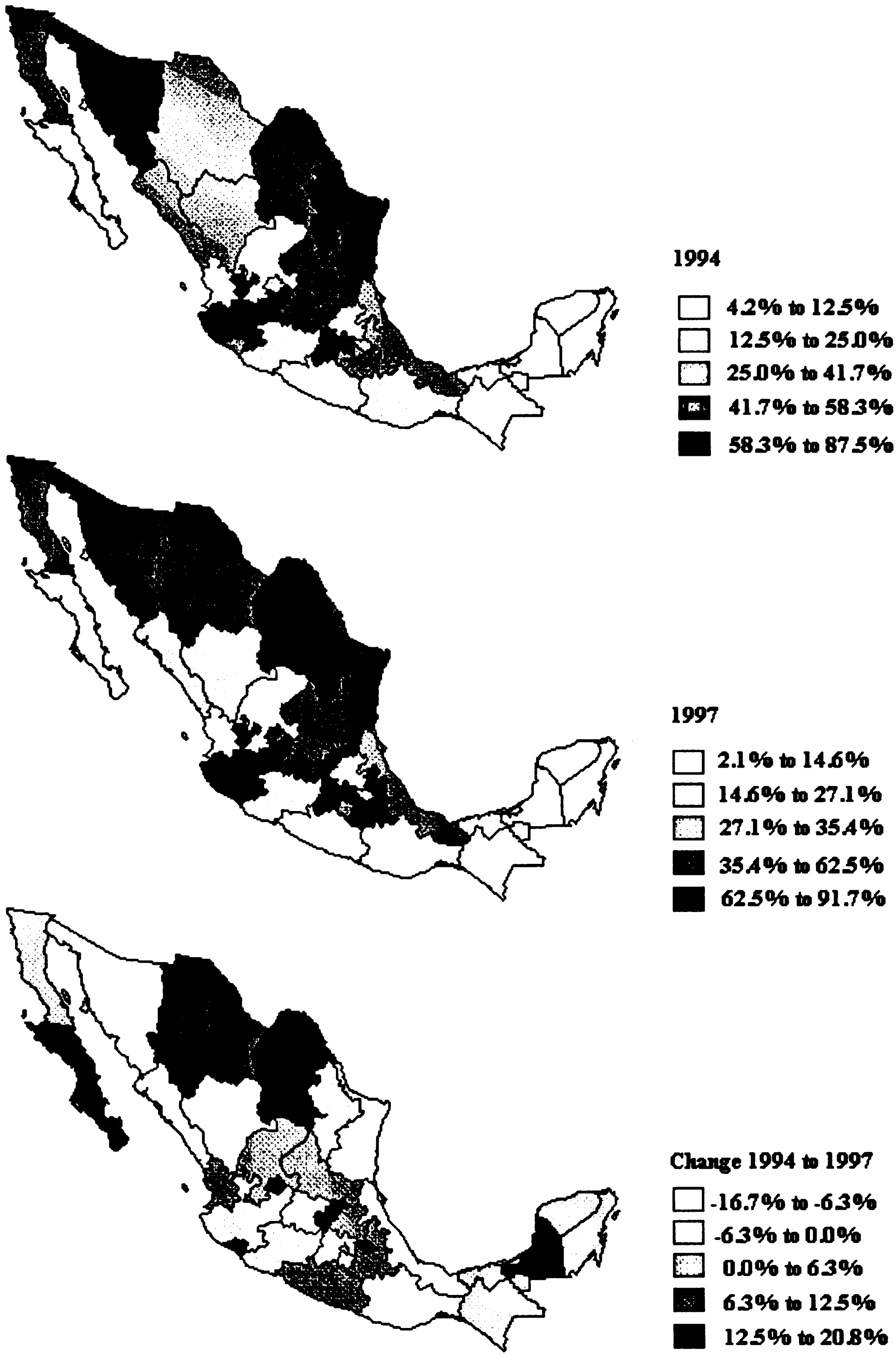
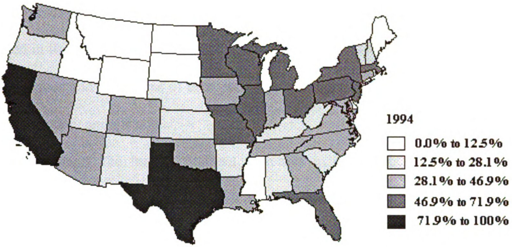
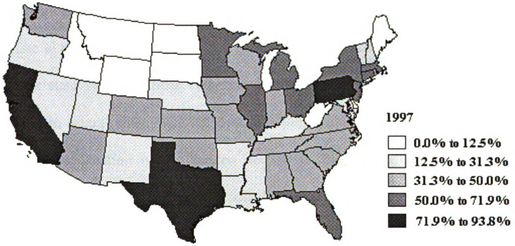
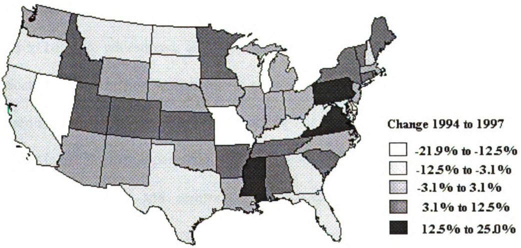


Figure 24. Complementarity in Instruments, US -- 1994-97







Assessment of Changes in Complementarity

Although binary matrices indicate that significant increases have taken place in the complementarity of both the United States and Mexico, no dramatic changes have occurred in the sources of supply and demand between 1994 and 1997. As maps indicate, border regions and core areas of both countries generally retained their dominant role as centers of supply and demand.

In general, the most prominent increases in overall complementarity among Mexican states are concentrated along the border and the area north of Mexico City. Notwithstanding the continued dominance of these regions, the most surprising changes in complementarity following 1993 include the substantial increase in demand of Campeche in the Yucatan Peninsula and the dramatic decrease in the complementarity of the border state of Tamaulipas. Whereas increases in demand in Campeche may be attributable to recent government attempts to exploit off-shore oil deposits in the Gulf of Mexico, no explanation of the sudden decline in demand in Tamaulipas is readily available. Changes, however, may be indicative of a greater degree of specialization in the state's economy or, less likely, a decline in competitiveness.

In the case of the United States, increased complementarity with Mexican states appears to be more widespread, although clear increases are apparent among states with historically less interaction with Mexican states. Though the most notable clustering of increased interaction is located in the western part of the country, moderate increases are also found in the South and parts of the Great Plains and Midwest.

Binary matrices and analysis of commodity-specific complementarity also illustrates differing levels of regional specialization and the complementary nature of interaction among certain commodity groups. Examples include similarities in the locational patterns of agricultural and food supply centers (centered on the Midwest) and the concentration of machinery, metals and transportation products in the traditional US manufacturing core. Among Mexican states a zone of high complementarity in most commodities extends from the border region to the Mexico City area.

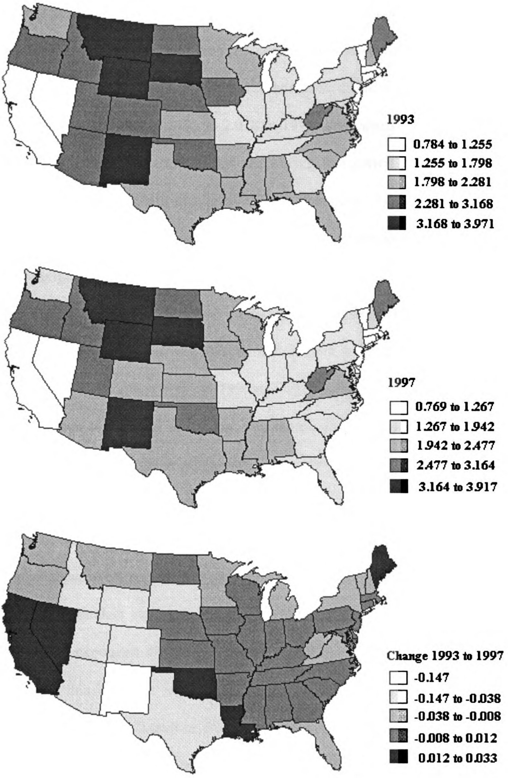
Origin-Specific Gravity Models

Due to the potential bias in gravity models cited above, only origin-specific models could be calibrated for 1993 and 1997 using BTS data supplemented by the 1993 US Commodity Flow Survey.

As the following maps reveal (Figure 25), the lowest distance decay exponents are concentrated in the eastern half of the United States, as well as California and Nevada. Moderate values are found along the border (with the exception of New Mexico) and the Midwest. The largest distance decay exponents, by far, are clustered in the Upper Great Plains.

The results of the origin-specific models coincide with the relationship proposed in *Hypothesis Four*. In general, states with small economies that are distant from the US-Mexico border exhibits greater sensitivity to distance. States with larger economies display smaller distance decay exponents. Though minor exceptions to this pattern can be found in New England and Nevada, *Hypothesis Four* is generally rejected. Geographically and economically peripheral states tend to have larger distance decay exponents.

Figure 25. Origin-Specific Distance Decay Exponents, 1994-97



As Figure 25 indicates, however, the most substantial decreases in distance decay exponents between 1993 and 1997 are found in the western half of the country, particularly among states with the largest distance decay exponents. Although some scattered decreases are found, distance exponents remained relatively stable or increased slightly in the Midwest and East. In general, however, distance decay values decreased (from an average of 2.089 in 1993 to 2.078 in 1997) and paired t-tests indicate that the moderate decline in the friction of distance during this period of time is statistically significant (2.686) at a significance level of 0.95. Therefore, *Hypothesis Five* is rejected. The greatest decreases in distance decay exponents occur among peripheral states rather than non-peripheral states.

As the literature review above indicates, distance decay exponents generally are thought to be stable over relatively short periods of time. In order to determine if changes in distance decay exponents between 1993 and 1997 are attributable to changes in trade patterns between the United States and Mexico or flows within the United States, a second origin-specific model was calibrated using CFS data for US states exclusively as origins and destinations. If no significant changes are identified in the distance decay exponents of this second model, then changes can be attributed exclusively to changes in trade flows between US and Mexican states.

Gravity models calibrated using the SRMSE reveal a slightly larger average distance decay exponents (2.092 for 1993 and 2.082 for 1997). Paired t-tests (2.229) indicate that this decrease in the friction of distance between 1993 and 1997 is statistically significant. Therefore, at least in these origin-specific models, significant decreases in the role of distance in impeding spatial interaction between the United States and Mexico between 1993 and 1997 cannot be attributed exclusively to the inception of NAFTA.

Total-Constrained Models

Total-constrained gravity models were calibrated using linear regression in order to examine overall changes in the friction of distance, as well as changes in total trade, trade by mode and trade by different commodity groups. Because the origin-specific models above provide some indication of changes in relative accessibility of US states as sources of supply, intercept and slope dummy variables have been included in total-constrained models to determine if Mexican border states experience a different level of distance deterrence. In general, border states are expected to exhibit less sensitivity to distance than non-border states. Therefore, the total-constrained models calibrated in this section will quantify changes in the overall friction of distance between the two countries, as well as differences in distance decay for Mexican border states. As mentioned above, the Chow test will be used to identify significant changes in the coefficients of regression models.

As Table 5 indicates, gravity models calibrated using linear regression provide only moderate goodness of fit. In general, supply, demand, distance and the dummy variables mentioned above explain less than 60 percent of the variation in trade flows. In all regression models a significance level of 0.95 has been chosen. Since the Chow test is an application of the F-test, a minimum value of 3.17 is needed (with 5 degrees of freedom in the numerator and greater than 120 degrees of freedom in the denominator) in order to reject the null hypothesis at a significance level of 0.99.

Table 5. ***Results of Total-Constrained Gravity Models***

Model	Equation	Adj. R^2	Prob
Total Trade 93	-36.891* + 1.638*Supply + 1.88*Demand - 2.242*Distance - 13.327*Border + 1.433*Slope	0.582	0.000
Total Trade 97	-36.749* + 1.534*Supply + 1.777*Demand - 1.953* Distance - 10.585*Border + 1.082Slope	0.587	0.000
Truck 93	-33.384* + 1.584*Supply + 1.825*Demand - 2.373*Distance - 14.544*Border +1.614*Slope	0.575	0.000
Truck 97	-32.363* + 1.446*Supply + 1.744*Demand - 2.166*Distance - 12.37*Border + 1.307Slope	0.589	0.000
Rail 93	-35.022* + 1.298*Supply + 1.708*Demand - 0.966*Distance + 15.416*Border - 2.282*Slope	0.509	0.000
Rail 97	-10.451 + 1.069*Supply + 0.671*Demand - 1.666*Distance + 20.032*Border - 2.51*Slope	0.39	0.000
Int. Goods 93	-41.266 + 1.486*Supply + 1.81*Demand - 1.033*Distance + 0.906Border - 0.515Slope	0.584	0.000
Int. Goods 97	-30.357* + 1.408*Supply + 1.651*Demand - 2.016*Distance - 12.688*Border + 1.356Slope	0.59	0.000
Non-Int. Goods 93	-44.009* + 1.662*Supply + 2.051*Demand - 1.745*Distance - 13.493*Border + 1.474*Slope	0.617	0.000
Non-Int. Goods 97	-46.501* + 1.723*Supply + 2.051*Demand - 1.714*Distance - 5.953Border + 0.457Slope	0.596	0.000
Lib. Goods 93	-33.27* + 1.464*Supply + 1.825*Demand - 1.885*Distance - 3.361Border + 0.268Slope	0.555	0.000
Lib. Goods 97	-38.048* + 1.459*Supply + 1.8*Demand - 1.277*Distance + 5.998Border - 1.008Slope	0.552	0.000
Non-Lib. Goods 93	-33.33* + 1.384*Supply + 1.928*Demand - 2.125*Distance - 4.684Border + 0.322Slope	0.59	0.000
Non-Lib. Goods 97	-41.551 + 1.551*Supply + 1.975*Demand - 1.709*Distance - 5.561Border + 0.486Slope	0.577	0.000

Total Trade

Linear regression models indicate that the overall friction of distance between the United States and Mexico declined from 2.242 in 1993 to 1.953 in 1997. In addition, intercept dummy variables are significant for border states for both years. Though border states display a significantly lower sensitivity to distance in 1993 (0.809), distance decay coefficients for border states were not significantly different from overall distance values in 1997. The Chow test (17.89) indicates that changes in distance coefficients of regression models for 1993 and 1997 are statistically significant. Therefore, *Hypothesis Three* is rejected. Significant changes in the overall friction of distance occurred between 1993 and 1997.

Table 6. ***Significance of Changes in Distance Decay Exponents***

Model	Distance Exponent 1993	Distance Exponent 1997	Significance (Chow)
Total Trade	2.242*	1.953*	17.89*
Truck	2.373*	2.166*	15.2*
Rail	0.966*	1.666	23.08*
Intermediate Goods	1.033*	2.016	5.63*
Non-Intermediate Goods	1.745*	1.714*	10.73*
Liberalized Goods	1.885*	1.277*	3.57*
Non-Liberalized Goods	2.125*	1.709*	10.59*

Trade by Mode

Truck Trade

Total-constrained models indicate that the friction of distance for truck trade declined from 2.373 to 2.166 between 1993 and 1997. Not surprisingly, since truck trade comprises more than 90 percent of total trade modeled above, intercept dummies are significant for both years and the 1993 slope dummy is significant. Models indicate that border states experienced a significantly lesser friction of distance (0.759) for truck trade than non-border states in 1993. However, as was the case with total trade, no significant differences existed in distance decay exponents for 1997. The Chow test (15.2) reveals that changes in distance decay coefficients between 1993 and 1997 are statistically significant. Therefore, *Hypothesis Eleven* is rejected. Significant decreases have occurred in the friction of distance for shipments by truck since 1993.

Trade by Rail

Because of the relatively sparse rail matrices and small volumes moved by rail, the goodness of fit of linear regression models for commodity shipments by rail are substantially weaker than those of other models. As a consequence, model results are somewhat more difficult to interpret. Models reveal that the friction of distance for trade by rail increased from 0.966 in 1993 to 1.666 in 1997. In addition, both 1993 and 1997 models indicate the Mexican border states are more sensitive to distance than non-border locations. As Table 5 shows, the distance decay exponent for border states in 1993 (3.248) increased markedly by 1997 (4.176), indicating an increasing degree of distance deterrence for rail shipments among border locations.

Although rail shipments generally appear to experience somewhat less distance deterrence than shipments by truck for both years, the model indicates that border states continue to experience a greater sensitivity to distance and that the friction of distance for rail shipments, among border states and non-border states alike, increased substantially between 1993 and 1997. The Chow test (23.08) confirms that increases in distance decay coefficients between 1993 and 1997 are statistically significant. As a consequence, though significant changes have occurred in the magnitude of distance decay parameters, *Hypothesis Ten* cannot be rejected. Rail shipments have become increasingly sensitive to distance since 1993.

Truck Trade vs. Rail Trade

For 1993 trade by truck exhibited an overall distance decay exponent of 2.373, whereas distance decay exponents for rail shipments are significantly lower (0.966). By 1997, however, the distance decay coefficient for truck trade had declined to 2.166 whereas shipments by rail, though still less sensitive to distance than trade by truck, had increased substantially (1.666). In the case of interaction with the US border, a different relationship was apparent. In general, Mexican border states exhibited dramatically less sensitivity to distance in the case of truck trade than movement by rail for both years.

Though the Chow test reveals that differences in distance decay coefficients for trade by mode are statistically significant for both 1993 (168.19) and 1997 (27.98), null *Hypothesis Sixteen* and *Hypothesis Seventeen* cannot be rejected. The Chow test indicates that rail, rather than truck shipments, are less sensitive to the impact of distance. Although rail shipments are becoming increasing sensitive to the friction of distance, their distance decay exponents are still significantly less than those for shipments by truck.

Trade by Commodity Type

Intermediate Goods

Surprisingly, total-constrained models indicate that the friction of distance for intermediate goods increased markedly between 1994 (1.033) and 1997 (2.016). However, models also reveal that no significant differences existed in the distance decay exponents of border states for either 1994 or 1997. Although the Chow test (5.63) indicates that increases in distance decay parameters are statistically significant, *Hypothesis Six* cannot be rejected. No significant decreases occurred in the distance decay exponents of intermediate goods between 1994 and 1997.

Non-Intermediate Goods

Gravity models reveal that the role of distance in impeding the movement of non-intermediate goods decreased slightly between 1994 (1.745) and 1997 (1.714). Intercept and slope dummy variables are significant for Mexican border states in 1994; the slope dummy variable indicates that the friction of distance for non-intermediate goods among border states was very low (0.271) in 1994. However, no statistical significance was found in slope dummy variables for 1997, indicating that border states did not experience significant differences in the friction of distance following implementation of NAFTA. Results of the Chow test (10.73) reveal that changes in regression model coefficients are statistically significant. Therefore, *Hypothesis Seven* is rejected. A significant decrease occurred in the distance decay exponents of non-intermediate goods between 1994 and 1997.

Intermediate Goods vs. Non-Intermediate Goods

Total-constrained gravity models suggest that intermediate goods displayed less sensitivity to the friction of distance than non-intermediate goods in 1993. However, models also indicate that intermediate goods had become more sensitive to the impact of distance than non-intermediate goods by 1997. The Chow test reveals that differences in distance decay exponents among intermediate and non-intermediate goods were statistically significant for both 1994 (8.27) and 1997 (10.96). Data analysis indicates that intermediate goods became more sensitive to distance than non-intermediate goods between 1994 and 1997. As a result, *Hypothesis Twelve* and *Hypothesis Thirteen* are rejected.

Liberalized Goods

Multiple regression models indicate that a substantial decrease took place in the role of distance in impeding the movement of liberalized goods between 1994 and 1997. Distance decay coefficients declined from 1.885 in 1994 to 1.277 in 1997. Models also reveal that border states did not experience significantly different distance decay functions in either 1994 or 1997. Since the Chow test (3.57) indicates that the decrease in regression model coefficients between 1994 and 1997 is statistically significant, *Hypothesis Eight* is rejected. A significant decline took place in the value of distance decay parameters for liberalized goods between 1994 and 1997.

Non-liberalized Goods

Total-constrained models also reveal substantial reductions in the friction of distance among non-liberalized goods between 1994 and 1997. Models indicate that the overall friction of distance declined from 2.125 in 1994 to 1.709 in 1997. As in the case of liberalized goods, border states did not display significantly different distance decay exponents for either 1994 or 1997. The Chow test (10.59) indicates that the decrease in distance deterrence is statistically significant. Therefore, *Hypothesis Nine* is rejected. Non-liberalized goods became significantly less sensitive to the friction of distance between 1994 and 1997.

Liberalized Goods vs. Non-liberalized Goods

Regression models suggest that liberalized goods were less sensitive to the impedance of distance than non-liberalized goods for both 1994 and 1997. In addition, models suggest that changes in the distance decay exponents of liberalized goods between 1994 and 1997 were greater than those in non-liberalized goods. The Chow test reveals that regression coefficients were significantly different in 1994 (17.81). In addition, significant differences in distance decay exponents persisted in 1997 (27.36). Therefore, *Hypothesis Fourteen* and *Hypothesis Fifteen* are rejected. Liberalized goods displayed significantly less sensitivity to distance in both 1994 and 1997.

Assessment of Gravity Models

In general, origin-specific gravity models corroborate the results of the analysis of complementarity above. Models confirm that core states, in general, have retained their dominance as the most accessible locations in the United States. Models also clearly illustrate the moderate improvement in the accessibility of peripheral locations in the United States following 1993. In addition, the relative stability in distance decay exponents among US states in the Midwest and the Northeast serves to reinforce the relative stability in complementarity among these locations.

Although origin-specific models confirm that a significant decrease occurred in the overall friction of distance between 1993 and 1997, they suggest that changes may not be due to the impact of NAFTA exclusively. Total-constrained models, calibrated with data for US origins and Mexican destinations exclusively, also reveal that significant changes have taken place. Though total-constrained models provide no indication of changes in the relative accessibility of origins, they do suggest that the overall friction of distance between the United States and Mexico declined after 1993. Though changes in distance decay cannot be attributed directly to the impact of NAFTA, models clearly confirm a pattern of decreasing friction of distance following implementation of the agreement.

The relatively weak goodness of fit of regression models, however, indicates that factors other than supply, demand and distance are responsible for a significant amount of variation in trade flows between different regions of the United States and Mexico. Possible factors include the role played by multinational corporations and maquiladoras, historical linkages between US suppliers and Mexican companies, the corporate structure and locational decisions of both US and Mexican businesses, and the demand for different commodities exerted by Mexican government agencies.

The results of total-constrained models generally conform to expected outcomes in the case of total trade, shipments by truck, non-intermediate, liberalized, and non-liberalized goods. However, the results of models for rail shipments and intermediate goods were particularly surprising. In addition, the inclusion of intercept and slope dummy variables for border states proved somewhat disappointing.

In most instances, dummy variables do not indicate significant differences in distance decay functions among border and non-border states. Interestingly, however, slope dummy variables for total trade, though significant 1993, are not significant for 1997. Therefore, total-constrained models indicate that border states did not experience significantly different distance decay exponents than non-border states following implementation of NAFTA. In other words, the relative accessibility of non-border states appears to have improved somewhat after 1993.

The generally poor performance of dummy variables may have resulted from the inclusion of the Mexico City region and the state of Jalisco with peripheral states in southern and southeastern Mexico. The tremendous diversity in the economies of these states probably does not permit reliable assessment of actual differences in distance decay exponents.

The most surprising outcome of total-constrained gravity models includes the tremendous increase in the friction of distance for rail shipments following 1993. Though rail transportation still proves less sensitive to distance than truck shipments, increases following 1993 may be the result of attempts by the Mexican government to privatize the country's rail system, ongoing government disinvestment and the increasing unreliability of the system. The extreme values of border states may be an indication of the relatively short hauls of certain commodities among US and Mexican border locations.

The dramatic increase in distance decay exponents for intermediate goods was also unexpected. This result suggests that the movement of these products has become increasingly concentrated in the border areas of both countries. This outcome is especially unexpected; following the inception of NAFTA, most experts expected that maquiladoras, and the resulting flow of intermediate goods, would become more dispersed throughout Mexico.

Chapter Five

INTERPRETATION AND CONCLUSIONS

Despite data limitations, this thesis has been moderately successful in assessing changes in the geographic structure of trade following implementation of the North American Free Trade Agreement. Although the gravity models calibrated in this thesis do not represent truly causal models, they do provide an indication of changes in spatial interaction, as well as the accessibility of places that generate and attract trade.

As the previous chapter reveals, border and core areas of both the United States and Mexico have retained their dominant roles as centers of supply and demand since the inception of NAFTA. However, results also suggest that the benefits of free trade, at least in a geographic sense, have been distributed differently, and unequally, in each country.

In the case of Mexico, binary matrices indicate that total complementarity has increased significantly since 1994 (Figure 2). In a spatial sense, more than two-thirds of Mexican states exhibited greater levels of demand in 1997. However, increased complementarity is clearly concentrated in the northern part of the country, from the US-Mexico border to the Mexico City area. An overall decline in interaction is apparent in the economically and geographically peripheral states of southern and southeastern Mexico.

Among US states, growth in complementarity is somewhat more widespread than in Mexico (Figure 3). Almost 80% of states displayed greater levels of supply in 1997 than in 1994. In addition, increases can be found in every region of the country. Decreases are relatively few, small and geographically dispersed. Origin-specific gravity models corroborate the results of binary matrices (Figure 25). Following implementation of NAFTA, most states displayed relatively less sensitivity to the friction of distance. However, US states displaying generally high levels of interaction with Mexico experienced little change in complementarity and magnitude of distance decay exponents. The most prominent improvements in total complementarity and transferability were experienced by states that historically have had less interaction with Mexico.

As Chapter One affirms, geographic differences in the distribution of benefits of NAFTA can be attributed to disparities in the overall economic development of Mexico and the United States and regional economic structures within each country. As a consequence, the outcomes identified above may be better understood in the context of two complementary frameworks -- Myrdal's (1957) theory of circular and cumulative causation and the "new" trade theory pioneered by Krugman (1994, 1995), among others.

Myrdal's theory of circular and cumulative causation posits that market forces tend to increase, rather than decrease regional inequalities (1957). Once a location has gained an initial advantage, economic growth tends to become concentrated there due to advantages such as economies of scale and greater specialization. These places become core areas, centers of economic activity like the manufacturing belt in the northeastern United States or the Mexico City region.

Concomitantly, the process of economic growth tends to produce two contrasting outcomes – spread effects and backwash effects. Spread effects represent positive outcomes such as the economic development of peripheral locations due to the continued expansion of core areas. Backwash effects refer to processes that bring about growth of core regions at the expense of the further decline and marginalization of peripheral areas. Whereas spread effects are most likely in economies that have achieved a certain level of economic development, backwash effects may be more likely, at least initially, in developing countries (Chorley and Haggett, 1967).

The widespread growth of complementarity throughout all regions of the United States and the substantial improvement in transferability among geographically and economically peripheral states may provide evidence of the spread effects of NAFTA. Conversely, the increasing concentration of demand among states in northern Mexico, in conjunction with the declining complementarity of states in the southern part of the country, may be an indication of Myrdal's backwash effects.

The "new" trade theory, associated primarily with Krugman (1994, 1995), is based on Myrdal's notion of circular and cumulative causation – increasing returns, economies of scale, and greater levels of specialization. The recent research of Hanson (1996, 1997), in particular, provides an indication of how trade liberalization measures such as NAFTA may have impacted upon the economic geography of the United States and Mexico.

Hanson (1997) asserts that trade policy plays a critical role in regional economic development and may diminish regional disparities in industrial employment and wages. However, he cautions that an even pattern of development will not result because trade agreements may shift industry to regions closer to foreign markets. In the case of Mexico, Hanson concludes that trade policies have prompted the decentralization of industrial activity from the area in and around Mexico City to the northern part of the country, especially along the US-Mexico border.

Analysis of changes in complementarity between 1994 and 1997 clearly supports Hanson's conclusions. From a geographic perspective, the locational changes in the demand of US imports among states in the northern part of Mexico is the likely result of the decentralization of economic activity following implementation of NAFTA in 1994.

Hanson (1996) also asserts that trade policies have had a significant impact on the economic geography of the United States. In fact, his research contradicts the view that changes in the Mexican economy are too small to have any real impact on the US economy. As industrialization has expanded in Mexican border states (the maquiladora program, primarily), manufacturing activity also has expanded in adjacent US border states. Notwithstanding the ongoing restructuring of the US economy, Hanson predicts that manufacturing activity will continue to relocate from the traditional manufacturing belt to locations closer to the border.

As this thesis reveals, the increasing relative complementarity of states in southern and western parts of the United States is likely evidence of the ongoing restructuring of the US economy. However, as Hanson's research suggests, locational changes between 1994 and 1997 in commodity groups such as chemicals, textiles, metal products and machinery (largely intermediate goods) also may be the result of decisions within specific industries to take advantage of industrial expansion in northern Mexico.

In conclusion, although this thesis illustrates problems in the calibration of gravity models with incomplete interaction matrices, it also indicates the potential promise of examining changes in the geographic, as well as commodity, structure of trade. Though the relative accessibility and importance of centers of supply and demand in both countries has not changed markedly, this thesis indicates that spatial interaction between the two countries has grown significantly since inception of NAFTA. These changes in the geographic structure of trade have generally been overlooked in the literature to date.

The results of this thesis also provide empirical support of the "new" trade theory. Although international economists have typically focused on changes in regional employment and wage structures to provide evidence of increasing returns and greater specialization, this study presents a geographic basis, focusing on notions of complementarity and transferability, in order to assess locational changes in economic activity.

This thesis also reveals several potential areas for further research. The limited explanatory power of traditional gravity models indicates the need to develop spatial interaction models that permit more comprehensive assessment of changes in the accessibility of origins and destinations and identify factors other than supply, demand and distance that determine levels of trade between US and Mexican states. In addition, as Hanson's research suggests, an opportunity exists for economic geographers to identify the spatial consequences of national policy decisions (such as NAFTA) and "new" forms of international trade on regional economies.

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