SPATIAL INTERACTION MODELING OF INTERREGIONAL COMMODITY FLOWS[1]

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Abstract. Drawing from both the spatial price equilibrium theoretical framework and the empirical literature on spatial interaction modeling, this paper expands models of interregional commodity flows by incorporating new variables into the model and using a flexible Box-Cox functional form. The recently released 1993 U.S. Commodity Flows Survey provides the empirical basis for estimating state-to-state flow models for 16 commodity groups over the 48 continental U.S. states. The optimized Box-Cox specification proves to be superior to the multiplicative one in all cases, and the selected variables provide new insights into the determinants of state-to-state commodity flows.

1. INTRODUCTION

Understanding the determinants of interregional commodity flows (CFs) is critical for both transportation infrastructure planning (highways, railroad tracks, river/port facilities) and regional development policies (location of activities, reducing regional disparities). Unfortunately, limited data availability has, in the past, hindered empirical research in this area. Prior to 1993, the 1977 U.S. commodity flows survey (**CFS**) was the most recent one. There has also been a dearth of such data in other countries (see Section 2). However, the U.S. Bureau of Transportation Statistics has recently released the results of the 1993 **CFS**, making them widely available. The structure of these flow data is very suitable for empirical analyses.

Using Brocker (1989) theoretical framework, this paper attempts to expand the empirical research on interregional CFs. It specifies a spatial interaction model that incorporates (1) variables similar to those used in past CF studies, (2) variables used in international trade models, and (3) a set of completely new variables. The selection of the variables is consistent with Brocker's framework and with inter-industry transactions considerations. For instance, the origins and destinations are characterized by proxy variables representing final and intermediate demands as mass variables. Adjacency and custom district dummy, distance, competing destination (Fotheringham, 1983), and intervening opportunities (Guldmann, 1999) variables are also considered. Instead of the multiplicative functional form used in the past, a flexible Box-Cox transformation specification is used. The model is estimated with the 1993 **CFS** data. The geographical coverage is the 48 US continental states, and the industry coverage is 16 two-digit manufacturing sector product groups.

The remainder of the paper is organized as follows. Section 2 consists of a literature review. The modeling methodology is presented in Section 3. Data are described in Section 4. The results are discussed in Section 5, and Section 6 concludes the paper.

2. LITERATURE REVIEW

Reed (1967), in one of the first empirical studies of CFs, analyzes the interactions of the Bengal Bihar area with the rest of India. The data are related to railroad shipments in 1962. Two separate models, for outflows and inflows, are used. Reed proposes to account for the effects of intervening and otherwise competing supplies and demands by introducing potential variables, as well as variables capturing redistribution and concentration effects. Chisholm and O'Sullivan (1973) use U.K. 1962 and 1964 CF data, over 78 zones and 13 commodity groups. Two models are used: the gravity model (GM) and the linear programming (LP) model. The single-constrained GM is retained. The R^2 obtained by comparing actual and estimated flows using the GM for 13 commodity groups vary between .24 for steel and .62 for food. The R^2 for the LP solutions are higher, especially for homogenous commodities. Black (1971, 1972) analyzes the properties and determinants of the distance exponent in the gravity model, using the 1967 U.S. **CFS** for 24 major shipper groups, and concludes that "(1) the greater the proportion of total shipments from the largest producer (or shipper), the lower the exponent, and (2) the greater the proportion of total flow which is local, the higher the exponent." Ashtakala & Murthy (1988) use a production-constrained gravity model to forecast CFs in Alberta. The R^2 varies between 0.71 and 0.88 for six commodity groups.

Although spatial interaction models have been extensively used in such areas as migration, commuting, shopping, and telecommunication, their application to CF modeling has remained very limited. The few studies reviewed so far focus on best-fitting very simple models, with little theoretical foundation. Black (1971, 1972), Chisholm and O'Sullivan (1973), and Ashtakala and Murthy (1988), employ a basic gravity model (with two mass and one friction variables), and their focus is on estimating the exponent of the distance variable. In addition to these simple models, Reed (1967) adds two more variables: supply/demand potentials, and redistribution/concentration effects. Except for Reed, no one has attempted to account for the effects of the spatial structure on flows (e.g., Fotheringham, 1983). Interestingly, the existence of these effects was first mentioned by Ullman (1967), but in a completely qualitative way. There is, however, a long tradition of using gravity models in empirical analyses of international trade flows, which are, of course, closely connected to interregional CF analyses. A good, recent example of such studies is provided by Frankel and Wei (1998), who assess the effects of regional trade arrangements on world trading patterns. Their data set covers sixty-three countries (3,906 exporter-importer pairs). The results indicate that larger economies trade more but not proportionately to their GNP. Bilateral distance has a significant effect. Contiguity and having language commonality also facilitate trade, but the effects of trade blocks are mixed.

3. MODELING METHODOLOGY

3. 1. Theoretical Background

Brocker (1989) shows that all forms of the gravity model (constrained, unconstrained, and elasticity constrained) are reduced forms of spatial price equilibria of interregional trade, using a modified version of the Spatial Price Equilibrium (SPE) model developed by Samuelson (1952). At each supply point i, there are firms supplying the commodities, and at each demand point j, there are firms and households demanding certain quantities ($y_{1j}, y_{2j}, \ldots, y_{ij}, \ldots y_{Ij}$) from the supply points ($i=1 \rightarrow I$). The supply firms are faced with f.o.b. prices, and the buying firms and households with c.i.f. prices. This model consists of four equations. A real-valued supply function is defined as follows:

$$S_i = \sigma_i(p_i, \mathbf{s}_i), \tag{1}$$

where S_i is the supply quantity at supply point i, p_i is the f.o.b. price at i, and $\mathbf{s}_i$ is a vector of other variables, such as prices of other commodities. σ_i is monotone, non-decreasing in p_i. For each demand point j, there is a demand correspondence, a point-to-set mapping which assigns the vector of O-D flows terminating at j, $\boldsymbol{y}_j = (y_{1j}, \ldots, y_{ij}, \ldots, y_{Ij})$, to the c.i.f. price vector, $\boldsymbol{q}_j = (q_{1j}, \ldots, q_{ij}, \ldots, q_{Ij})$, so that

$$\mathbf{y}_j \; \varepsilon \; \delta_j(\mathbf{q}_j, \mathbf{w}, \mathbf{d}_j), \tag{2}$$

where **w** is a vector of parameters that measure the supply characteristics influencing purchase choices, $\mathbf{d_j}$ is a vector measuring demand characteristics, including income, prices of other commodities, etc. The third equation defines c.i.f. prices:

$$q_{ij} = p_i + c_{ij}, \tag{3}$$

where c_{ij} is the transportation cost between i and j. And the fourth equation states the equilibrium conditions:

$$\sum_j y_{ij} = S_i \; \forall \, i. \tag{4}$$

A spatial price equilibrium is characterized by prices and quantities satisfying (1) – (4), which represent the *explicit (or structural)* form of the trade model, with both prices and quantities as endogenous variables. Eliminating prices leads to the reduced form of the model, where equilibrium flows are directly assigned to the vector of exogenous variables,

$$(\boldsymbol{s}, \boldsymbol{w}, \boldsymbol{d}, \boldsymbol{c}) = (s_1, \ldots, s_I, w_1, \ldots, w_I, d_1, \ldots d_J, c_{11}, \ldots, c_{IJ}).$$

The reduced form is denoted by $\zeta = (\zeta_{11}, \ldots, \zeta_{ij}, \ldots, \zeta_{IJ})$, so that, for any equilibrium flow matrix $\boldsymbol{Y}^* = (\boldsymbol{y}^*_1, \ldots, \boldsymbol{y}^*_J)$, we have

$$\boldsymbol{Y}^* = \zeta\, (\boldsymbol{s}, \boldsymbol{w}, \boldsymbol{d}, \boldsymbol{c}). \tag{5}$$

Of course, there is no closed mathematical formulation of ζ. One way to think about this function is to solve the equilibrium problem for a wide range of combinations of values for the input parameters $(\boldsymbol{s}, \boldsymbol{w}, \boldsymbol{d}, \boldsymbol{c})$, for instance over a grid. The resulting flow values Y_{ij}^* could then be regressed over the input parameters, providing an approximation of the function ζ. An alternative approach is to view (5) as a general guide for the selection of simpler, and empirically estimable functional forms. Brocker (1989) shows that the generalized gravity form

$$\zeta_{ij}\ (\boldsymbol{s}, \boldsymbol{w}, \boldsymbol{d}, \boldsymbol{c}) = \boldsymbol{a}_{ij}\ (\boldsymbol{s}, \boldsymbol{w}, \boldsymbol{d}, \boldsymbol{c})\ f(c_{ij})\ \boldsymbol{b}_i\ (\boldsymbol{s}, \boldsymbol{w}, \boldsymbol{d}, \boldsymbol{c}) \tag{6}$$

is consistent with (5). Equation (6) suggests that the origin and destination factors, $\boldsymbol{a}_i$ and $\boldsymbol{b}_j$, may be functions of the whole vectors $(\boldsymbol{s}, \boldsymbol{w}, \boldsymbol{d}, \boldsymbol{c})$, and not only of the components of these vectors associated with i or j, exclusively. In the standard gravity model, we would have

$$\boldsymbol{a}_i = \boldsymbol{a}_i\ (s_i, w_i), \tag{7}$$

$$\boldsymbol{b}_j = \boldsymbol{b}_j\ (d_j), \tag{8}$$

that is, the origin mass factor is only a function of origin the supply variables, and the destination mass factor is only a function of the destination demand variable. Equation (6) clearly suggests that supply and demand variables for other locations k ($\neq$ i, j) may be included in $\boldsymbol{a}_i$ and $\boldsymbol{b}_j$. The following section presents the adaptation of model (6) to an empirically estimable model.

3. 2. The Empirical Commodity Flow Model

3. 2. 1. Variables

a) Origin Variables

The origins serve as supply points but also consume part of this supply, and therefore the variables chosen to represents the origin should be proxies for supply conditions and demand conditions at the origin.

Sectoral employment (**oemp**) and sectoral value-added (**ovlad**) are used as proxy variables for sectoral production at the origin, and represent supply characteristics. Their expected signs are positive. Wholesale employment (**owsem**) is used to measure the effect of redistribution activities on commodity out-shipments. As wholesale employment increases, the out-shipment of the commodity is expected to increase. Wholesale activities may also facilitate consumption of the commodity by the final demand sector at the origin. Thus, the expected sign of the coefficient of **owsem** is positive.

Total population (**opop**) and personal income per-capita (**opipc**) are two proxy variables for demand conditions at the origin. Although the origins are supposed to be associated with supply conditions for commodity out-shipment, local final demand at the origin may have significant effects. Their expected signs are negative. As local final demand increases, the out-shipment of the commodity decreases due to increased local consumption.

The average plant size (**oaps**) is estimated by dividing total sectoral employment by the total number of establishments in that sector. It is intended to capture scale or diversification effects in the industry. Theoretically, as the plant scale of an industrial sector increases, total production and thus total out-shipments in that industry are supposed to increase due to increased production efficiency. However, the two-digit level aggregation may not reflect this effect properly. In other words, the total amount of out shipments by small firms may outrun the out-shipments of the larger firms, because many smaller firms may be characterized by more product diversity, more attractive to export markets than a few larger firms. For this reason, this variable may either (1) have a positive sign, indicating that scale effects control out-shipments or that the out-shipment market is dominated by a few large firms, or (2) have a negative sign, implying that the diversification effect dominates the industry or the market is shared by many small-scale diversified companies. [For a theoretical discussion of these effects, see Krugman (1980)].

b) Destination Variables

The destinations serve as demand points, and destination variables should mainly be proxies for commodity demands, both intermediate and final. Manufacturing employment (**dmnem**) is the proxy for intermediate demand; personal income per-capita (**dpipc**) and total population (**dpop**) are to measure final demand conditions; and wholesale employment (**dwsem**) is a proxy to measure redistributions effects at the destination. All of their expected signs are positive.

c) Geographical Variables

Distance is the most conventional friction variable used in all spatial interaction models. It takes different forms, like highway distance, great circle distance, etc. In this study, the average distances of all hauled commodities are used. The expected sign for the distance variable is always negative, indicating that the interaction between the origin and the destinations decreases as the distance between them increases.

Two specific variables are employed to capture the effect of the spatial configuration of states: competing destination (**cd**), and intervening opportunities (**io**) variables. These variables may be viewed as integrating into the model the demand/supply effects at locations other than the origin (i) and destination (j). With reference to Equations (5) and (6), these variables represent at least a portion of the vectors (**s, w, d**). The **cd** variable measures the accessibility of a specific destination to all other destinations. It is estimated using a destination total employment and the distance between two destinations. Mathematically it is expressed as follows:

$$CD_{ij} = \sum_k TE_k / d_{kj} \quad k \neq (i,j) \qquad (9)$$

There is no presumption about the sign of this variable. A negative sign indicates that there is competition among destinations, and as other destinations k get closer to destination j, the amount of the commodity terminating at j decreases. A positive coefficient sign implies agglomeration effects: flows increase as other destinations get closer to destination j, and thus make it more attractive to flows.

The intervening opportunities (**io**) variable is defined by a formula similar to (9). The distance used in Eq. (9) is taken as d_{ki} instead of d_{kj}. According to the intervening opportunities concept, flows to a destination decrease when the opportunities between the origin and the destination increase. Just like clusters at destinations, the **io** variable may be used to describe the spatial configuration of the clusters around origins. According to this idea, a positive sign indicates that when other origins are getting closer, thus implying an economic concentration around the origin, the flow to destination increases. This would suggest possible agglomeration effects at the supply level. However, a negative sign would suggest that the destinations in the origin clusters may act as competing destinations, thus reducing the flow to the destination. An alternative interpretation of a negative sign could be linked to agglomeration diseconomies. The larger the cluster, the larger the negative effects (e.g., congestion), hence the lesser the demand and the flow to destination.

Three dummy variables are also used. First, the adjacency dummy (**adjncy**) measures whether having a common physical border has an effect on commodity flows between states. The sign is expected to be positive: trade flows between neighboring states increase, because of better business information, regional cultural commonalities, etc. Imports and exports are included in the 1993 CFS, from and up to the custom districts where the commodity enters or leaves the US. For this reason, two custom district dummy variables, **ocddmy** for the origin and **dcddmy** for the destination, measure the effects of foreign trade at either origin or destination, on commodity flows. The magnitudes of their coefficients depend on the foreign trade share of interregional commodity flows. These variables may have either a negative or a positive sign. A positive **ocddmy** indicates that the sector may have a significant foreign import of the commodity, while a negative sign implies a significant foreign export of the commodity. A positive **dcddmy**, on the other hand, implies that the sector may have a significant foreign export, while a negative sign would point to imports. States with custom districts are coastal (Ocean or Great Lakes) and along the borders with Canada and Mexico (Montana, North Dakota, and Arizona).

3. 2. 2. Functional Form

The commodity flow between two points can be written with the variables specified above, and may be expressed in the framework of Equation (6), with:

$$F_{ij} = a_i\,(ovlad, oemp, opop, opipc, oaps, owsem, io, ocddmy)\, f_{ij}\,(dist, adjcny) \\ b_j\,(dwsem, dmnem, dpop, dpipc, dcddmy, cd) \quad (10)$$

where $\boldsymbol{a_i}$ is the supply point factor, $\boldsymbol{b_j}$ the demand point factor, and $\boldsymbol{f_{ij}}$ the interaction factor. Equation (10) could be, in line with past empirical research, represented by a multiplicative functional form, which would become linear in the logarithms of the dependent and independent variables. However, other functional forms may be acceptable, and there are no strong theoretical reasons to prefer one functional form to another. It is therefore reasonable to allow for the endogenous selection of the functional form. The Box-Cox transformation, wherein the variable X is transformed into the variable $X^{(\lambda)}$ according to

$$X^{(\lambda)} = (X^{\lambda} - 1)/\lambda, \quad (11)$$

is ideally suited to this purpose (Box and Cox, 1964). Two different transformation parameters are considered: one for all the independent variables (λ) and one for the dependent variable (θ). Dummy variables, however, are not transformed. The Box-Cox model can be expressed as

$$\frac{Y^{\theta} - 1}{\theta} = a_0 + a_1 X_1 + a_2 \frac{X_2^{\lambda} - 1}{\lambda} + \ldots + a_n \frac{X_n^{\lambda} - 1}{\lambda} + \varepsilon \quad (12)$$

where ε is assumed a normally distributed error, with $E(\varepsilon)=0$ and $E(\varepsilon\,\varepsilon') = \sigma^2 I$. The Box-Cox transformation (11) is continuous at $\lambda = 0$, because $X^{(\lambda)}$ tends toward lnX when $\lambda \to 0$. Thus, the linear and the multiplicative functional forms are simply specific points (λ=1 and λ=0) on a continuum of forms allowing for different degrees of independence and interaction among the variables.

The fundamental criterion for comparing the infinite number of a priori possible models is how well they are able to explain the data, with the best model maximizing the likelihood of the original observations. Once the optimal functional form (λ^*, θ^*) has been determined, it is possible to test whether an alternate form (λ, θ) is significantly different from the optimal one, using a χ^2 test.

4. DATA SOURCES AND PROCESSING

Four main data sources are used in this study: the 1993 CFS; the 1993 County Business Patterns; the 1992 Censuses of Manufactures (Bureau of the Census); and the Annual State Personal Income (Bureau of Economic Analysis). The CFS provides the data for the dependent (CF) and distance variables. The other sources provide the data for the independent variables.

4. 1. Dependent Variable

Data for the dependent variable, **flow,** are drawn from File 9 of the 1993 **CFS**, and measure the value (Million $) of out-shipments from each origin state to every other state, for each of 16 commodity groups (see Table 1), primarily defined at at the two-digit SIC level (the highest level of disaggregation for O-D flows in the CFS). The file includes a total of 83,232 flow observations, with 22,476 of them missing (27 %), because of data disclosure and sampling problems, but these missing flows represent only 12 % of the total flow. This rate varies from a high 36 % for leather products to a low of 3 % for food and kindred products. Missing observations are eliminated from the database. The geographical coverage is the 48 U.S. continental states. Imported products shipments are included after they leave the importer's domestic location for another location. Export shipments are also included until they reach the port of exit from the U.S. Shipments through a foreign country, with both the origin and destination in the U.S., are included. Descriptive statistics for the dependent flow variables across all commodities are presented in Table 2.

Table 1. Commodity Groups Codes and Definitions

Codes	Definitions
20	Food and Kindred Products
24	Lumber or Wood Products
25	Furniture of Fixture
26	Pulp, Paper, or Allied Products
28	Chemicals or Allied Products
29	Petroleum or Coal Products
30	Rubber of Plastics Products
32	Clay, Concrete, Glass or Stone Products
33	Primary Metal Products
34	Fabricated Metal Products
35	Machinery, excluding electrical, Products
36	Electrical Machinery Products
37	Transportation Equipment
38	Precision Instruments
39	Miscellaneous Freight Shipment
75	Textile, Apparel and Leather Products

4. 2. Independent Variables

The adjacency dummy variable, **adjncy**, is defined as equal to 1 if the origin and destination states have a common border, and 0 otherwise. The custom district variables, **ocddmy** and **dcddmy**, are defined as equal to 1 if the state contains at least one custom district, and 0 otherwise. All the employment variables are drawn from the County Business Patterns (CBP) database, and include (1) origin sectoral employment, **oemp**; (2) origin wholesale employment, **owsem**; (3) destination manufacturing employment, **dmnem**; and (4) destination wholesale employment, **dwsem**. The origin average establishment size variable, **oaps**, is estimated by dividing the origin sectoral employment by the number of establishments in that sector. The numbers of establishments are drawn from the CBP. The value-added variable, **ovlad**, is drawn from the 1992 Census of Manufactures. The state personal income per-capita variables, **opipc** and **dpipc**, and the state population variables, **opop** and **dpop**, are drawn from the Annual State Personal Income database of the Bureau of Economic Analysis (BEA). The distance variable, **dist**, is directly derived from the 1993 CFS as average hauled distance. File 9 in the 1993 CFS has both tonnage and ton-miles values for each commodity group. Dividing ton-miles by ton values, the average hauled distance for each commodity group between each O-D pair is estimated. The competing destination variable, **cd**, and the intervening opportunities variable, **io**, are estimated using distance and total employment.

4.3. Statistics Overview

Table 2 present statistics for all the variables across all commodities. The total value of the 16 commodity groups traded in the U.S. within and across state-lines was $ 5,160 billions in 1993. The largest share characterizes food and kindred products, with around 15 %. The second largest share pertains to transportation equipment, with around 12 %. The third largest group is chemical products, 10.5 %. The other significant product groups are non-electrical machinery (8 %), and textile, leather and apparel (7.5 %).

Table 2. Descriptive Statistics for 1993-All Commodities Combined

Variable	N	Mean	St. Dev.	Minimum	Maximum	Sum
Flow ($M)	26023	92	280	0	7800	2385928
Cd	26023	201995	178751	16323	771064	5256512406
Io	26023	197308	179558	16323	771064	5134543484
Dist (miles)	26016	1241	757	40	3519	32285248
Opipc ($)	26023	20660	2841	15468	29602	537622216
Opop	26023	5473805	5785073	460000	30380000	142444834000
Oemp	26023	22100	32709	1	284042	575108111
Owsem	26023	143180	153831	7807	783658	3725983058
Ovlad ($M)	26023	1730	2889	0	21698	45031541
Oaps	26023	71	94	2	1715	1754252
Dmnem	26023	417532	390355	11285	1898885	10865447978
Dwsem	26023	146218	153495	7807	783658	3805026717
Dpipc ($)	26023	20736	2881	15468	29602	539601756
Dpop	26023	5585155	5766049	460000	30380000	145342500000

The highest per-ton value product group is precision instruments, with $ 2,566. The cheapest or bulkiest product group is clay, concrete, glass and stone products, around $12/ton. Other high-value product groups include electrical and non-electrical machineries, transportation equipment, and textile, leather, and apparel products. Lumber and wood products, coal and petroleum products, and primary metal products belong to the low value/bulky products groups. It is expected that low-value commodities are characterized by short hauls, and high-value ones by long hauls, reflecting the share of transportation costs in total production costs. With approximately 12 % in shipments share, California displays a spatial concentration in manufacturing production and consumption, possibly at both the intermediate and final levels. The second largest spatial concentration is in Texas, around 8 % of the U.S. interstate trade. The same 12 states, namely, California, Texas, Illinois, Ohio, New Jersey, Michigan, New York, Pennsylvania, North Carolina, Georgia, Florida, and Indiana, export/import approximately 50 % to 60 % of all shipments in the US.

As mentioned earlier, foreign trade flows are included in the CFSs in flows to and from US custom states. In terms of foreign export in 1993, non-electrical machinery products have the highest share (19.4 %). The other high-export sectors are clay, concrete, glass and stone products (17.7 %), electrical machinery (14.6 %), transportation equipment and precision instruments (around 11 %). The product groups with high shares of foreign imports include clay, concrete, glass and stone products (24.2 %) , non-electrical machinery (22.3 %), electrical machinery (20.7 %), transportation equipment (16.2 %), coal and petroleum products (16 %), textile, leather and apparel (15 %), furniture and fixture products (13 %,), and precision equipments (11.1 %).

5. RESULTS

The results of the estimation are presented in Tables 3 and 4. Overall, the selected variables are generally significant in explaining interregional commodity flows, with the expectated signs. It is also noteworthy that the optimized Box-Cox specification is always statistically superior to the linear-in-logarithms specification, which has been a mainstay of past empirical work.

A common physical border significantly increases commodity exchanges between contiguous states. For 15 out of the 16 commodity groups, the dummy variable **adjncy** is significant at the 5 % level and positive. This result is consistent with the estimates of all empirical, gravity-type models of international trade that include a contiguity dummy variable. While an increasing distance guarantees a declining interaction, this decline is attenuated among contiguous states. The ability to obtain better business information about supplies and/or consumers, as well as possible cultural commonalities, are most likely factors explaining this phenomenon. It is also likely that a business trying to expand its market beyond state boundaries will first focus on neighboring states before expanding beyond, thus ensuring a differential advantage to these states. It is also possible that short-haul transportation between contiguous states may be different and less expensive than for greater distances.

The foreign trade dummy variables, **ocddmy** and **dcddmy,** do not display the same level of consistency as **adjncy**. Only 5 commodity groups have a significant **occdmy** at the 5 % level, and 4 groups at the 10 % level. The other foreign trade variable, **dcddmy,** performs even more poorly: it is significant at the 5 % level for 3 commodity groups, and at the 10 % level for only 2 groups. Focusing on **ocddmy**, we note that seven out of nine significant coefficients are negative (commodity groups 20, 24, 30, 33, 34, 36, 37), which suggests that foreign exports taking place at the origin node reduce the interregional commodity outflows from these nodes. These results are consistent with the significant foreign export volumes of sectors 36 (non-electrical machinery) and 37 (transportation equipment), and, to a lesser extent, of sector 20 (food), 30 (rubber and plastics), and 33 (primary metals). In contrast, the coefficient is positive for commodity group 26 and 29, which suggests that when the origin node imports pulp and paper, and petroleum/coal products, these foreign imports stimulate interregional flows out of these origin nodes. In the case of petroleum, this result is very much consistent with the importance of foreign oil imports in the U.S. economy.

The competing destination variable, **cd**, is uniformly negative and significant in all groups: in 15 groups at the 5 % level, and 1 group at the 10 % level. These results suggest that competition effects at destinations are strong determinants of interregional commodity flows. As other destinations are physically closer (clustered) to a specific destination, the flow of commodities reaching this destination decreases. Every other factor remaining constant, this clustering absorbs part of the flow that would have ended at this destination under a less clustered configuration. This result is consistent with similar effects empirically uncovered in the case of other spatial interactions (e.g., migrations, telecommunications).

The intervening opportunities variable, **io**, does not have the same highly consistent effects as **cd**. It displays mostly negative signs. 10 groups have negative signs at the 5 % significance level, 1 group has a negative sign at the 10 % level, and 2 groups have a positive and significant **io** coefficient. Overall, competition effects at the supply level appear dominant. Destination nodes clustered around the origin serve as alternative destinations for the commodity, and absorb past of the flow that would have ended at the selected destination.

The distance variable, **dist,** is always negative and highly significant for all commodity groups. Distance can be viewed as a proxy for transportation cost, and increasing transportation costs are an obvious deterrent to trade. Also, from an information viewpoint, the farther away the lesser the information about business opportunities, and hence the lesser the interactions. The distance coefficients for sectors 35 through 39 are generally lower (in absolute terms) than those for the other

Table 3. The Model Variable Coefficients and Their Significance Levels Across Commodity Groups (20-32)

	20		24		25		26		28		29		30		32	
adjncy	1.62	*	1.82	*	0.50	*	0.51	*	1.84	*	8.25	*	1.14	*	1.37	*
ocddmy	-0.27	*	-0.20	**	-0.10		0.27	*	0.01		1.84	*	-0.17	**	-0.12	
dcddmy	0.21	**	0.07		0.20	**	-0.01		0.16		0.33		-0.05		0.08	
Cd	-0.85	*	-1.84	*	-1.13	*	-0.60	*	-0.23	*	-0.41	**	-0.42	*	-0.77	*
Io	-0.67	*	-1.28	*	-0.58	*	-0.50	*	-0.20	*	-0.18		-0.09		0.26	*
dist	-2.20	*	-2.22	*	-1.64	*	-1.62	*	-1.29	*	-3.00	*	-1.07	*	-1.41	*
opipc	-0.09		2.22	*	0.09		-0.37		0.00		-2.19	*	-0.69	*	0.14	
opop	-0.57	*	0.09		0.07		0.22	**	-0.10		-0.45	**	-0.33	*	-0.29	
oemp	0.87	*	-0.23		1.38	*	0.52	*	0.45	*	1.95	*	0.12		0.96	*
owsem	0.90	*	0.42		0.68	*	0.15		0.23	*	0.78	*	0.75	*	0.07	
ovlad	1.05	*	2.37	*	-0.06		0.49	*	0.60	*	-0.12		0.68	*	0.36	**
oaps	-0.88	*	0.33		0.45	*	-0.16		-0.71	*	-2.85	*	-0.01		-0.66	*
dmnem	0.19	*	1.02	*	-0.09		0.37	*	0.10	*	0.03		0.24	*	0.36	*
dwsem	1.02	*	0.76	*	0.71	*	0.67	*	0.73	*	0.28		0.42	*	0.35	*
dpipc	1.05	*	3.40	*	2.42	*	0.84	*	-0.12		-0.10		0.44	*	1.26	*
dpop	0.47	*	1.12	*	1.25	*	0.17		0.05		0.31		0.24	*	0.65	*
Lambda	0.08	*	0.02		0.04	*	0.09	*	0.11	*	0.19	*	0.10	*	0.07	*
Theta	0.19	*	0.17	*	0.12	*	0.18	*	0.18	*	-0.24	*	0.19	*	0.13	*

* Significant at 5 % level ** Significant at 10 % level

Table 4. The Model Variable Coefficients and Their Significance Levels Across Commodity Groups (33-75)

	33		34		35		36		37		38		39		75	
adjncy	0.85	*	1.22	*	1.52	*	1.30	*	0.06		1.51	*	1.47	*	1.05	*
ocddmy	-0.22	**	-0.22	*	0.04		-0.18	**	-0.60	*	0.18		0.01		-0.21	
dcddmy	-0.36	*	0.11		0.17	**	-0.08		0.07		0.23	*	0.13		-0.12	
cd	-0.48	*	-0.54	*	-0.42	*	-0.67	*	-0.56	*	-0.26	*	-0.58	*	-2.61	*
io	-0.41	*	-0.21	*	-0.15	*	-0.02		0.29	*	0.09		-0.16	*	-1.12	**
dist	-1.57	*	-1.26	*	-0.86	*	-0.96	*	-1.24	*	-0.70	*	-0.93	*	-2.04	*
opipc	0.04		-0.30		-0.26	**	-1.16	*	-0.79	*	-1.01	*	0.69	*	1.59	
opop	0.20		-0.31	*	-0.32	*	-0.45	*	-0.30	*	-0.98	*	-0.13		-3.10	*
oemp	1.23	*	-0.04		0.16	*	1.54	*	0.15	*	0.92	*	0.78	*	3.79	*
owsem	0.30	**	0.90	*	0.88	*	0.81	*	0.41	*	1.42	*	0.57	*	3.46	*
ovlad	-0.21	**	0.86	*	0.49	*	-0.36	*	0.59	*	0.07		0.26	*	-0.36	**
oaps	-0.11		0.25		0.07		-1.03	*	-0.80	*	-0.85	*	0.04		-1.35	*
dmnem	0.49	*	0.24	*	0.09	*	0.05		0.16	*	-0.11	**	0.05		1.48	*
dwsem	0.29	*	0.35	*	0.47	*	0.56	*	0.18	**	0.49	*	0.32	*	0.64	
dpipc	-0.45		0.37	*	0.26	**	1.52	*	0.76	*	0.98	*	1.05	*	4.82	*
dpop	0.57	*	0.43	*	0.33	*	0.93	*	0.42	*	0.58	*	0.82	*	3.22	*
Lambda	0.07	*	0.10	*	0.11	*	0.07	*	0.13	*	0.08	*	0.07	*	-0.03	
Theta	0.18	*	0.21	*	0.20	*	0.18	*	0.14	*	0.16	*	0.19	*	0.13	*

* Significant at 5 % level ** Significant at 10 % level

sectors, which indicates that the shipping distances for these goods are greater. This is consistent with the value per weight of these commodities, which ranges from $748/ton to $ 5,566/ton. The latter characterizes precision instruments (group 38), which have the lowest distance coefficient (-0.70). The other groups, which have values per weight ranging from $11/ton to $427/ton, have distance coefficient varying from –1.07 to –2.20.

The origin state personal income per capita, **opipc**, is presumed having a negative sign: when the local consumption of the commodity increases, its export shipments decrease. This is generally verified for the commodity groups that are involved in final consumption (e.g., petroleum, rubber, machinery, transportation equipment, precision instruments). In 1993, 6 groups have negative signs at the 5 % significance level, and 2 groups at the 10 % level. The origin state total population variable, **opop**, is similar to **opipc**: both **opop** and **opipc** are used as surrogate for local final consumption. 8 commodity groups have negative and significant signs at the 5 % level, and 2 groups at the 10 % level. When significant, **opop** and **opipc** have generally the same sign, which supports their use as measures of origin final consumption.

The origin sectoral employment, **oemp,** is generally positive and significant, as hypothesized: 13 commodity groups are positive at the 5 % significance level. The other sectoral production variable, **ovlad**, is also mostly positive: 9 commodity groups have positive signs at the 5 % level, and 1 group at the 10 % level.

Scale or diversification effects for origin state sectoral establishments have been tested using the average establishment size variable, **oaps**. 8 of the 16 group have significant negative signs, implying that these sectors are characterized by “diversification effects”. Only 1 group, furniture and fixture products, displays a positive and significant coefficient in both years, pointing to economies of scale effect.

Another important result of the study is that wholesale employment, representing redistributive activities at both the origin and destination, is important in facilitating interregional commodity flows, by buying commodities from the production sector and reselling them to the intermediate and final demand sectors: 13 groups have a significant positive sign for **owsem** (12 of which are at the 5 % level), and 14 groups have a positive **dwsem** (13 of which are significant at the 5 % level).

The destination manufacturing employment, **dmnem**, is a proxy for the effects of intermediate demand sectors at the destination, and it is presumed to have a positive sign. This presumption is verified for 11 commodity groups at the 5 % significant level.

Increasing consumption opportunities at the destinations were expected to positively affect the outflows, and this is also confirmed by many positive and significant parameter estimates for destination state per capita income and destination state population. The variables representing final demand at destinations, **dpipc** and **dpop**, are expected to be positive. In 1993, this is verified for 13 commodity groups for both variables.

Based on their likely demand structure, it is possible to group commodities into three main groups. (1) Those that are mainly inputs to final demand sectors, (2) those that are mainly inputs to intermediate demand sectors, and (3) those that are inputs to both demand sectors.

(1) Product group 25, furniture and fixture; product group 29, coal and petroleum; product group 36, electrical machinery; product group 38, precision instruments; and products group 39, miscellaneous manufactured products, are primarily inputs to final demand sectors. According to the empirical findings, in none of these groups is the intermediate demand proxy variable, **dmnem**, very significant, confirming the hypothesis. The origin local demand for product group 25 is not significant, probably because the production of this commodity is spatially concentrated, with economies scale (**oaps** is positive and significant in only this product group). Product group 29 however, is very sensitive to origin local demand conditions but not to destination local demand, probably because this product is highly sensitive to shipping distance. The other groups, however, are sensitive to both origin and destination final demands.

(2) Product group 24, lumber and wood; product group 28, chemical products; product group 32, clay, concrete, glass and stone products, and products group 33, primary metal products are the sectors that are producing primarily for intermediate demand sectors, and the variable **dmnem** is very significant for all four groups, whereas the final demand variables are not significant. Although lumber and wood; clay, concrete, glass and stone; and primary metal products may also be assumed to be

important for final demand sectors via the construction sector, the performances of the final demand variables do not support this assumption.

(3) Product group 20, food and kindred products; product group 26, pulp and paper products; product group 30, rubber and plastic products; product group 34 fabricated metal products; product group 35, non-electrical machinery; product group 37, transportation equipment; and product group 75, textile, apparel and leather products, on the other hand, are demanded by and supplied to both intermediate and final demand sectors. Variables representing both final and intermediate demand sectors are highly significant in these products groups.

6. CONCLUSIONS

This paper has expanded past models of interregional commodity flows by incorporating new explanatory variables and using the flexible Box-Cox specification. Based on input-output considerations and in order to differentiate intermediate from final commodity demands, the new variables include more detailed descriptions of the economies of the origin and destination states, such as employment and value added for the commodity sector at the origin state, wholesale employment at both ends, manufacturing employment at the destination state, and population and per-capita income at both ends. In addition, the average establishment size for the commodity at the origin is intended to measure scale or diversification effects. The competitive or agglomerative effects of the economic spatial structure are captured with competing destination and intervening opportunities variables. In addition to the average hauling distance between states, the model includes dummy variables measuring whether (1) having a common physical border, and (2) the origin or destination states being custom districts, have an effect on flows.

Overall, the results show that the selected variables and Box-Cox functional form are successful in explaining flow variations, with the following findings: (1) the distance effect is negative and highly significant, with bulkier products hauled over shorter distances; (2) the adjacency effect is significant, with neighboring states trading more with one another, even after accounting for distance; (3) the impact of the spatial structure is of the competitive type in most cases; (4) the effects of imports and exports are significant for specific commodities; (5) wholesale activities at both origins and destinations are important facilitators of commodity flows; (6) except in one case (furniture), flows increase with product diversification; and (7) the role of intermediate and final demands for the commodities are clearly reflected by the selected employment, population and per-capita income variables.

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