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Journal
Transportation, 35(1)

ISSN
0049-4488

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Publication Date
2008

Peer reviewed

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October 2007

Transportation **35(1)**, 2008, 1-22

ABSTRACT

Using input-output (I-O) accounts provided by the U.S. Department of Commerce, this study investigates the aggregate relationships between the transportation and communications inputs demanded (directly and in total) by all industries in the U.S., and compares the results across time. We analyzed five pairs of Spearman correlations of transportation and communications demands (utilities, manufacturing, and overall) using the direct and total coefficient tables from the ten benchmark input-output years spanning 1947 to 1997. To correctly represent the overall economy-wide relationship, each industry (direct table) or commodity (total table) in the correlation was weighted proportionately to the monetary value of its contribution to the U.S. economy. In the analysis using direct I-O coefficients, we found a pattern of predominant complementarity between transportation and communications manufacturing, and substitution between transportation and communications utilities. There are intriguing indications, however, of a shift from substitution to complementarity in the latter case, beginning around 1987. In the analysis using total I-O coefficients, we found a pattern of complementarity for all years between transportation and communications manufacturing, and a pattern changing from substitution to complementarity for the remaining four pairs (transportation manufacturing and communications utilities; transportation utilities and communications manufacturing; the utilities pair; and the overall pair). Thus, from the industrial perspective (which constitutes a sizable proportion of the total demand for communications and transportation), it is not realistic in modern times to expect telecommunications to substitute for travel. Nevertheless, further research is needed into the specific causes of the observed shift from substitution to complementarity, and current trends should continue to be monitored for any changes.

Keywords: complementarity, ICT impacts on travel, input-output analysis, substitution

1. Introduction

It is considered a widely desirable social goal to reduce traffic congestion, fuel consumption, and emissions. Since many public policies have been promulgated on the assumption that telecommunications will be a useful trip reduction instrument, investigation of the relationship between telecommunications, or information and communication technologies (ICT), and travel has been a fertile area of research for several years. Numerous disaggregate and aggregate studies have been conducted, with mixed results regarding whether there is a substitutive or complementary relationship between telecommunications and travel. At the disaggregate level, empirical evaluations of several telecommuting programs (e.g. Quaid and Lagerberg 1992; Mokhtarian *et al*. 1995) seemed to support the substitution prospect. In the meantime, however, some scholars (e.g. Salomon 1985; Mokhtarian 1990, 2002) began to point out that substitution was not the only possible impact of telecommunications on transportation. In particular, it was argued that a very likely impact would be the generation of more travel, or complementarity. Mokhtarian and Meenakshisundaram (1999) suggest that the empirical findings in support of substitution may be a consequence of the short-term, disaggregate, narrow focus of the typical telecommuting (or other application) evaluation, and that when the focus is broadened to examine all communications across the entire population over a period of time, it is more likely that a complementarity effect will emerge.

Only a few aggregate studies have been conducted to date on this question. Selvanathan and Selvanathan (1994) examined three sectors of consumer demand, namely private transportation, public transportation, and communications, using a simultaneous equation system for consumer demand calibrated with annual consumption expenditures and population time series data (1960-1986) for the United Kingdom and Australia. They found that all three sectors have pairwise relationships of substitution. On the other hand, a more elaborate replication of this approach (Choo *et al.* 2007, forthcoming), using more recent data for the U.S., corroborated the finding of substitution at the most aggregate level of sector categorization, but identified predominantly complementary relationships at finer levels of category disaggregation. Choo and Mokhtarian (2005, 2007) explored the aggregate relationships between measures of telecommunications (local telephone calls, toll calls, and mobile phone subscribers) and travel (vehicle-miles traveled, transit passengers, and airline passenger-miles traveled) activities, using structural equation modeling of national time series data (comprising industrial as well as consumer activity) in the U.S. (1950-2000). They found that most significant causal relationships were complementary.

Most of the quantitative studies conducted to date, especially the disaggregate ones, have focused on the consumer demand for transportation and communications. Yet Plaut (1997) noted that in Europe, approximately two thirds of expenditures on transportation and communications services are made not by households but by industry. According to the 1992 benchmark input-output (I-O) accounts in the U.S., 57.2% of total expenditures on transportation utilities and 46.0% of total expenditures on communications utilities were for intermediate inputs by industries (while expenditures for personal consumption were 24.0% and 44.2%, respectively; the remaining expenditures were for other final uses such as capital investment, exports or governmental consumption). In 1997, the proportion of industrial uses had increased: 62.3% of expenditures on transportation utilities and 48.1% on communications utilities were for use by industries (with personal consumption at 22.8% and 43.2%, respectively). Thus, it is even more important to understand relationships between transportation and communications for industry – the focus of this study – than it is to do so for consumers.

Both substitution and complementarity effects are likely to occur for industry (see, e.g., Niles 1994). Substitution effects can arise when information or effective personal presence is conveyed using ICT (whether telephone, fax, e-mail, videoconferencing, remote sensing, or other product/service) in lieu of physical object delivery or passenger travel. The use of ICT to more efficiently manage travel can also lead to reductions. For example, the adoption of electronic data interchange (EDI) and other ICTs in support of just-in-time (JIT) supply chain strategies can improve shipping performance (Srinivasan *et al*. 1994) and reduce inventory costs (Wang and Seidmann 1995; Milgrom and Roberts 1988; Zhuang 1994); automatic identification technologies such as Global Positioning System (GPS) for tracking freight vehicles have resulted in fuel savings and reductions in deadheading time (McFarlane and Sheffi 2003).

On the other hand, JIT manufacturing processes and the use of ICTs such as bar codes and radio frequency identification (RFID) tags in retail stocking have arguably increased travel with their emphasis on more frequent deliveries (Holmes 2001; Zhuang 1994), in some cases reported to have noticeably increased local congestion (Shiomi *et al*. 1993, cited in Moinzadeh *et al*. 1997). The complementarities inherent among "rapid mass data communications, production equipment with low setup, wastage, and retooling costs, flexible design technologies, product designs that use common inputs, very low levels of inventories …, and short production cycle times" (Milgrom and Roberts 1990, p. 526) presumably increase manufacturing efficiency, lower costs, and hence support the production of more goods, requiring more transportation (Milgrom *et al.* 1991). And advanced information technologies have enabled the increasing globalization of commerce (Boudreau *et al*. 1998), which has increased both the demand for goods and the distances over which they are transported.

As explained further in Section 3, in using input-output data to analyze communications – travel relationships it is useful to distinguish two categories in each case: manufacturing (physical objects, such as phones, computers, and vehicles) and utilities (services, such as telephone service or trucking). Each transportation category (manufacturing and utilities) could be related to each communications category, for four possible combinations. Overall, eight types of relationships could occur, since each relationship could be either substitution or complementarity (if there is a significant relationship at all). Table 1 summarizes some examples of each of those eight potential types of relationships for industry. All of these relationships are plausible, and are likely to be occurring simultaneously. Thus, a given empirical result should be viewed as the net outcome of these counteracting influences, and it is reasonable to hypothesize that either substitution or complementarity might be the net outcome in any given case. It is also possible, of course, that an apparent "no relationship" result is actually the net outcome of both processes at work and approximately equally counteracting each other.

[Table 1 goes about here]

Plaut (1997) applied input-output analysis [1] to analyze the relationships between communications and transportation as inputs to 44 different industry groups for nine countries of the European Commission in the year 1980. For all nine countries, she concluded that there was a complementary relationship between communication and travel in the industrial context. That is, industries requiring large amounts (in monetary value) of transportation service inputs tended

[1] Input-output analysis is an analytical framework and an economic tool to describe the interdependence of various industries in an economy. In the decades since Wassily Leontief (1936) introduced I-O analysis and conducted path-breaking research with it (Leontief 1951), I-O analysis has become widely used as a quantitative model not only in planning processes (Sand 1988; Szymer 1986), but also in policy design (Baumol and Wolff 1994).

to require large amounts of communication service inputs.[2] Later, Plaut (1999) investigated the relationship between communications and transportation in the countries of Israel (in 1988), Canada (in 1991) and the United States (year not clearly specified). Her findings include complementary relationships for all the countries analyzed in the paper, although the format of the I-O accounts is different since each country uses a different set of industry categories.

Hence, only one of these studies (Plaut 1999) examines (to some extent) the relationships for the case of the U.S., as part of an international comparison of Israel, Canada, U.S.A. and Europe. However, her studies are restricted to one year rather than multiple years for the U.S., and which year is not specified. Further, the analysis focused only on the utilities sectors (i.e. services) of transportation and communications, whereas (as indicated above) relationships can also be expected with respect to the manufacturing sectors (i.e. goods) for those inputs. In addition, the correlation calculations gave equal weight to the inputs required by each industry, regardless of whether a given industry constitutes an enormous portion of the overall economy, or a tiny one. Finally, with respect to the methodological approach, the study seems to be inconsistent (to some extent) in terms of comparing results across countries. Plaut reported only direct input-output coefficients for the U.S. while both direct and total I-O coefficients are reported for the other countries. And for most countries, Plaut uses the Spearman correlation as the indicator of the relationship between transportation and communications inputs, while the Pearson correlation is inexplicably used for the U.S. alone.

The major purpose of this paper is to investigate the aggregate relationships between transportation and communications as commodity inputs for each U.S. industry and industrial outputs of the final end-user demand for U.S. commodities, using input-output direct and total requirement coefficients, respectively, provided by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce, and to compare the results across time. Since total requirement coefficients include amounts required indirectly as well as directly, the results of the total analysis might differ considerably from the direct requirements.

Thus, this study takes Plaut's approach, and extends it in several important ways. First, we analyze U.S. input-output requirement coefficient matrices for ten points in time within the period from 1947 to 1997. The points in time comprise the ten benchmark years for the I-O accounts for U.S. industry during that period – that is, years at which I-O relationships are

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[2] Plaut notes that although this is not the classical economic definition of complementarity, it is similar in concept.

recalculated from scratch rather than adjusted from a previously-calculated matrix. It is of interest to investigate how relationships between transportation and communications inputs (for the direct analysis) and outputs to meet final demand (for the total analysis) may be changing over time. Second, this study explores relationships not only between transportation and communications as utilities, as Plaut did, but also between transportation and communications manufacturing, and between manufacturing and utilities, which Plaut did not do. Interrelationships among six industry categories are analyzed in this study: (i) transportation manufacturing (TM), (ii) communications manufacturing (CM), (iii) transportation utilities (TU), (iv) communications utilities (CU), (v) all transportation manufacturing and utilities (AT, categories (i) + (iii)), and (vi) all communications manufacturing and utilities (AC, categories (ii) + (iv)). Lastly, the economic contribution-based weight (ECBW), which is introduced in this study, is applied to each I-O coefficient of the corresponding industry and commodity. In other words, in calculating the correlation between transportation and communications requirement coefficients, every coefficient is weighted proportionally to the monetary value of the contribution of the output industry (for the direct analysis) and the demanded commodity (for the total analysis) to the U.S. economy.

The rest of this paper is organized as follows. The following section explains the application of input-output analysis to this study. Section 3 describes the collection and manipulation of data on the I-O accounts. Section 4 discusses the methodological approach, and the interpretation of the correlation coefficients, which constitute the heart of the analysis. Then, the empirical results are presented in Section 5. Finally, the concluding section briefly reviews the major results, discusses some limitations of the study, and proposes potential further research.

2. Methodological background

2.1. Concept of the input-output methodology

In the U.S., the input-output accounts are composed of five basic tables[3]. Here, we focus on tables 3 (the commodity-by-industry direct requirements matrix, or input coefficient matrix) and

[3] The five tables are (1) make, (2) use, (3) commodity-by-industry direct requirements (the input coefficient matrix), (4) commodity-by-commodity total requirements, and (5) industry-by-commodity total requirements. Industries are viewed as making and using commodities, which can be purchased by consumers.

5 (the industry-by-commodity total requirements matrix). The input coefficient matrix is derived from the following equation:

$$a_{ij} = \frac{X_{ij}}{X_j}\,, \qquad (1)$$

where a_{ij} is the *i-j*th input coefficient of the *direct* coefficient matrix, X_{ij} is the monetary value of inputs from sector *i* directly demanded by sector *j*, and X_j is the monetary value of the gross output of sector *j*. Thus, the *i-j*th coefficient represents the monetary value of inputs of commodity *i* that are required to produce a dollar of gross output in industry *j*.

Since the sum of the demand for industry sector *i* over all industry sectors *j* and final end user demand for sector *i* should be the same as the total output of industry *i*, it is represented as follows:

$$X_i = \sum_{j=1}^{N} X_{ij} + F_i\,, \qquad (2)$$

where X_i is the total output of industry sector *i*, X_{ij} is the intermediate input from *i* to *j*, F_i is the final end user demand for sector *i*, and N is the number of industries in the I-O table. Then, substituting equation (1) into equation (2), the input-output model can be described as follows:

$$X_i = \sum_{j=1}^{N} a_{ij} X_j + F_i\,. \qquad (3)$$

In matrix form, equation (3) can be written:

$$\begin{bmatrix} X_1 \\ X_2 \\ . \\ X_i \\ . \\ X_N \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1j} & \dots & a_{1N} \\ a_{21} & a_{22} & \dots & a_{2j} & \dots & a_{2N} \\ . & . & . & . & . & . \\ a_{i1} & a_{i2} & \dots & a_{ij} & \dots & a_{iN} \\ . & . & . & . & . & . \\ a_{N1} & a_{N2} & \dots & a_{Nj} & \dots & a_{NN} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ . \\ X_j \\ . \\ X_N \end{bmatrix} + \begin{bmatrix} F_1 \\ F_2 \\ . \\ F_i \\ . \\ F_N \end{bmatrix}. \qquad (4)$$

Rearranging each equation to group the *X*s together gives the following system of equations:

$$X_1 - (a_{11}X_1 + a_{12}X_2 + ... + a_{1i}X_j + ... + a_{1N}X_N) = F_1$$
$$X_2 - (a_{21}X_1 + a_{22}X_2 + ... + a_{2i}X_j + ... + a_{2N}X_N) = F_2 \quad (5)$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$X_N - (a_{N1}X_1 + a_{N2}X_2 + ... + a_{Ni}X_j + ... + a_{NN}X_N) = F_N \ .$$

Therefore, letting A be the direct input coefficient matrix, F be the vector of final (end user) net industrial output demanded, and X be the column vector of gross industrial outputs, equation (5) in matrix form becomes $X – AX = F$, or $(I – A)X = F$, giving:

$$X = (I - A)^{-1} F \ , \quad (6)$$

where I is the identity matrix.

The inverse matrix $(I–A)^{-1}$ is called the "Leontief Inverse Matrix" or "Multiplier Matrix," and can be represented as follows:

$$(I - A)^{-1} = \Lambda = \begin{bmatrix} \lambda_{11} & \lambda_{12} & \cdots & \lambda_{1N} \\ \lambda_{21} & \lambda_{22} & \cdots & \lambda_{2N} \\ . & . & \cdots & . \\ \lambda_{N1} & \lambda_{N2} & \cdots & \lambda_{NN} \end{bmatrix} . \quad (7)$$

Thus, X_i can be represented as

$$X_i = \sum_{j=1}^{N} \lambda_{ij} F_j \quad . \quad (8)$$

The above "Multiplier Matrix" is also known as the *total coefficients matrix*, which is constructed from the direct coefficients matrix A through matrix inversion. Equation (8) shows that $\lambda_{ij} F_j$ is the dollar amount of commodity j contributing to the total output in industry sector i. The total requirement coefficient λ_{ij} constitutes the weight of the final demand for commodity j in computing the total output required in industry sector i, *i.e.* the dollar-valued change in output in industry sector i resulting from a unit (one dollar) change in the final demand for commodity j. For example, if there is a unit (one dollar) change in the final demand for motor vehicles, it generates a dollar-valued change in output in required industries (steel, tires, and other components) which includes direct and indirect effects because there is an extended interaction in the process of production, *i.e.* each product used as inputs to motor vehicles will itself require assorted inputs to produce it. Specific examples and more detailed explanations can be found in Lee (in progress).

In the simplified discussion above, the input coefficients matrix is square. However, it is not square in actuality. For example, at the most aggregate level of industry categorization, the use table (from which the direct input coefficients table is created) has nine top-level industry categories for its columns, but ten top-level commodity categories – including the additional "noncomparable imports"[4] category – for its rows. At a more disaggregate level (the 97 by 94 matrix), there are three more commodity categories than industry categories: noncomparable imports; scrap, used and secondhand goods[5]; and rest of the world adjustment to final uses[6]. It is complex to create the total requirement coefficients matrix in this case. However, the Bureau of Economic Analysis (BEA) provides total requirements tables obtained through the appropriate mathematical derivations (US DOC 1998), and this study uses those tables.

2.2. Application of input-output analysis to this study

In this study, the direct and total coefficients matrices A and Λ are used to analyze the relationship between transportation and communications, as commodity inputs for each industry (for the direct analysis) and as industry outputs to the final demand for each commodity (for the total analysis). We conduct a cross-sectional analysis for each time period, and then compare results across the 10 benchmark years.

For the direct analysis, let A_{Tjt} be the direct input coefficient of transportation for output industry j in year t, and similarly for A_{Cjt} for communications. "T" and "C" are generic indicators referring to transportation and communications; in application they could refer to transportation or communications utilities, manufacturing, or both combined. The subscript *"j"* ranges over all industry sectors, e.g. 94 industries in 1992 – including, based on the nine top-level industries, agriculture, forestry, and fisheries (#1), mining (#2), construction (#3), manufacturing (#4), transportation, communications, and utilities (#5), wholesale and retail

[4] "Noncomparable imports include imported services that are not commercially produced in the United States, and goods and services that are produced abroad and used abroad by U.S. residents" (Planting and Kuhbach 2001, p. 51).

[5] "Scrap is a secondary product of many industries, and used goods are sales and purchases typically between final users. Industry output is zero because there is no primary producing industry" (Planting and Kuhbach 2001, p. 51).

[6] "The commodity entries include adjustments among personal consumption expenditures (PCE) and government expenditures to eliminate counting the expenditures by foreign residents in both exports and PCE or government expenditures" (Planting and Kuhbach 2001, p. 51).

trades (#6), finance, insurance, and real estate (#7), services (#8), and special industries (#9). Thus, A_{Tjt} is the dollar value of transportation required to produce one dollar of output of industry j in year t. As shown in Figure 1a, $\underline{A}_{T\bullet t}$ and $\underline{A}_{C\bullet t}$ are the row vectors of direct coefficients for commodities transportation and communication, across industries j for a given year t. The question of interest is, when industry j's requirement for transportation commodity inputs is high, does its requirement for communication inputs also tend to be high (indicating positive correlation, and therefore complementarity)? Or when its requirement for one type of commodity is high, does its requirement for the other type tend to be low (negative correlation, and therefore substitution)?

[Figure 1 goes about here]

Thus, the basic indicator of interest to the direct analysis is:

$$Corr_t(\underline{A}_{T\bullet t},\ \underline{A}_{C\bullet t}), \quad (9)$$

where $Corr_t$ means correlation across industries j for year t..

For the total analysis, the question of interest is, when commodity j's total requirement for transportation outputs in year t (λ_{Tjt}) is high, does its total requirement for communications outputs in year t (λ_{Cjt}) also tend to be high (complementarity: positive correlation)? Put more simply, when a lot of transportation is required to deliver a dollar of commodity j to final end users, does a lot of communications also tend to be required? Or when the requirement for one is high, does the other tend to be low (substitution: negative correlation)? Therefore the basic indicator of interest to the total analysis is:

$$Corr_t(\underline{\lambda}_{T\bullet t},\ \underline{\lambda}_{C\bullet t}), \quad (10)$$

where $\underline{\lambda}_{T\bullet t}$ is the total requirement coefficients vector for the transportation industry across commodities j for year t, $\underline{\lambda}_{C\bullet t}$ is the total requirement coefficients vector for the communications industry across commodities j for year t, and $Corr_t$ means the correlation coefficient of T and C for year t, across commodities j. As schematically illustrated in Figure 1b, this quantity is obtained by computing the correlation of the T and C row vectors of the industry-by-commodity total requirements matrix.

3. Data collection and manipulation

3.1. Data Collection

There are two types of input-output matrices for the U.S. economy: benchmark and annual accounts. An annual table is an updated version of a previous benchmark table, using the current year data for output, which is published at a less detailed level. The benchmark I-O accounts are published essentially every 5 years, with the annual accounts filling in the remaining years (U.S. DOC 1998). Due to their obvious superiority, we restricted this study to the benchmark tables. The benchmark I-O matrices are available on the Internet (see http://www.bea.doc.gov/bea/dn2/home/benchmark.htm) for the years 1947, 1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, and 1997. The data for direct and total coefficients between 1947 and 1977, inclusive, were originally available only in paper-based versions published by the U.S. Department of Commerce. However, total coefficients for the years between 1947 and 1977, and direct coefficients for 1967, have recently been made available on the website as text files (later years are available in spreadsheet formats). In this paper we use the combined (paper-based and electronic) versions of direct requirements I-O matrices, and electronic versions of all the total requirements I-O matrices.

3.2. Data Manipulation

3.2.1. Classification of Industries

The input-output accounts can be classified into nine top-level industry categories, as noted in Section 2.2. Among those categories, this study focuses on demands for the manufacturing sector (#4) and the transportation, communications, and utilities sector (#5), which have transportation and communications components. Figure 2 shows the nine major industry categories, followed by the subcategories defined for our purposes. The manufacturing sector (#4) is divided into three categories (#10, #11 and #12 in our sequential numbering system): #10 (All Transportation Manufacturing), #11 (All Communications Manufacturing), and #12 (Manufacturing except Transportation and Communications). The transportation, communications, and utilities sector (#5) can also be classified into three categories: #13 (All Transportation Utilities), #14 (All Communications Utilities), and #15 (Utilities except

Transportation and Communications). In Figure 2, the lower portion lists the exact groups comprising each of the selected categories, for three different time periods: (1) 1947 through 1982 benchmarks, (2) 1987 and 1992 benchmarks, and (3) 1997 benchmark[7].

[Figure 2 goes about here]

3.2.2. Selected Industry Categories for Analyses

The direct and total requirement coefficients are manipulated to compute the correlation coefficients across all industries, among five pairs of the following six selected categories[8]:

- Selected Category #10: All Transportation Manufacturing (16+17+18+19+20);
- Selected Category #11: All Communications Manufacturing (21+22);
- Selected Category #13: All Transportation Utilities (23+24+25+26+27)[9];
- Selected Category #14: All Communications Utilities (28+29);
- Selected Category #30: All Transportation Manufacturing and Utilities (10+13); and
- Selected Category #31: All Communications Manufacturing and Utilities (11+14).

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[7] In 1997, the classification of industries was changed to a format based on the North American Industry Classification System (NAICS). Prior to that year, the Standard Industrial Classification (SIC) system was used as the basis. For this study, we modified the NAICS to make it as consistent as possible with the SIC system of previous benchmark years.

[8] We considered including the industry category titled "Computer and Data Processing Services" (SIC 737) as one of our communications-related categories in the analysis. But we chose not to do so, for three reasons. First, that category lies in an entirely different top-level industry group (#8, services) than do the others we analyze (#4, manufacturing and #5, utilities). Second, the SIC 737 category is not uniform across the 10 benchmark tables (only available as a sub-category under "Business and Professional Services, except Medical" (industry #73) in 1972 1977, and 1982). Third, correlation analyses (on the most disaggregate case) defining "Communications Utilities" (#14, see Table 2) to include industry #73A do not show very different results compared to the original ones.

[9] This category consists of *for-hire* transportation services that are offered by transportation companies (e.g. railroads, trucking companies, and air carriers) to industries. However, transportation services are also rendered *in-house* (own-account), and in the benchmark I-O accounts these are included under the own-industry inputs demanded by either the sending or the receiving industry, not individually classified (US DOT 1999). To provide a more comprehensive measure of the requirement for transportation services (both for-hire and in-house), the Bureau of Transportation Statistics (BTS) of the U.S. Department of Transportation and the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce jointly developed the Transportation Satellite Accounts (TSAs). Thus, TSAs include a separate in-house transportation services sector, category #65G (data available at http://www.bea.gov/industry/index.htm#satellite, accessed on June 4, 2007). Unfortunately, however, the TSAs were published only for two years (1992, a benchmark year, and 1996, a non-benchmark year), and discontinued thereafter. We conducted the 1992 analysis for both the benchmark accounts and the TSAs (in which we included category #65G among the components of category #13, Transportation Utilities); the TSA results are described in footnote 11 below.

Specifically, we analyze the pairwise correlations across industry of the demand for each transportation sub-category with the demand for each communications sub-category, and similarly for the two overall categories: Corr (#10, #11), Corr (#10, #14), Corr (#11, #13), Corr (#13, #14), and Corr (#30, #31). Corr (#13, #14) is the analysis that Plaut (1999) conducted, for one (unspecified) year.

4. Methodological approach and interpretation of correlation coefficients

Saunders *et al*. (1994) indicated that using input-output analysis to identify the relationship between telecommunications and economic activity might have a potential problem: the lack of proper weighting according to the proportions of total communications consumption by each industrial sector (e.g., although the service and agriculture sectors consume 50% and 1% of all communications services, respectively, both sectors weighted equally in the analysis). We agree with the implication that sectors should not be weighted equally in the analysis, but in our context, it seems more appropriate to weight each sector based on its overall contribution to the economy rather than its relative consumption of communication or transportation services or manufacturing.

Thus, before computing the correlation coefficients, we apply an Economic Contribution-Based Weight (ECBW) to weight each industry according to its monetary contribution to total industry output (for the direct analysis), and to weight each commodity by its contribution to total commodity demand (for the total analysis). The initial weighting factor for each industry j and commodity j (for direct and total, respectively), $IECBW_j$, is as follows:

$$IECBW_j = \frac{X_j}{\sum_{j'=1}^{J} X_{j'}} \times J \, , \qquad (11)$$

where j = industry (for the direct analysis) or commodity (for the total analysis) index; X_j = total value of production of industry j (jth row-sum of the make table) for the direct analysis, or total value of production of commodity j (jth column-sum of the make table) for the total analysis; and J = number of industries (for the direct analysis) or number of commodities (for the total analysis) contributing non-zero production to the economy.

Since the weights are required to be integers, the $IECBW_j$ is rounded to the nearest integer to create the $ECBW_j$, and the j-th case is replicated $ECBW_j$ times in computing the correlation[10]. Since the input-output coefficients are not normally-distributed, we use the Spearman rank-order correlation rather than the Pearson correlation in this analysis. In our context, the equation for the Spearman rank correlation is

$$r_s = \frac{\sum_j [(R_{jC} - \overline{R}_C)(R_{jT} - \overline{R}_T)]}{\sqrt{\sum_j [(R_{jC} - \overline{R}_C)]^2 \sum_j [(R_{jT} - \overline{R}_T)]^2}}, \tag{12}$$

where R_{jC} is the rank of the jth element of the vector $\underline{A}_{C\bullet t}$ or $\underline{\lambda}_{C\bullet t}$, R_{jT} is the rank of the jth element of the vector $\underline{A}_{T\bullet t}$ or $\underline{\lambda}_{T\bullet t}$ (R_{jC} , $R_{jT} \in \{1, 2, \ldots, J\}$), $\overline{R}_C$ is the mean of the ranks R_{jC} ($\overline{R}_C = \frac{\sum_{j=1}^{J} R_{jC}}{J}$), and $\overline{R}_T$ is the mean of the ranks R_{jT}. In the Spearman correlation analysis, the smallest value in the vector gets rank #1, and the largest value in the vector gets rank #J.

The interpretation of the Spearman correlation coefficient is similar to that of the Pearson coefficient, except based on ranks rather than the original values: if, when R_{jC} is above average ($R_{jC} > \overline{R}_C$), R_{jT} tends to be as well (or if when R_{jC} is below average, R_{jT} tends to be as well), the numerator and hence r_s will be positive. Conversely, if, when R_{jC} tends to be above average R_{jT} tends to be below average, then the numerator and hence r_s will be negative. Thus, if the correlation coefficient is positive, it implies that the relationship between the two categories is complementarity because the two outputs tend to be used (or not to be used) together. On the other hand, if a correlation coefficient is negative, it means the relationship between the two inputs is substitution: industries that require more of the one tend to require less of the other.

We used the "Spearman correlation analysis" module of the statistical analysis software package SPSS (Version 13.0) to produce the correlation coefficients, with p-values, for the five combinations described in the previous section, across the ten benchmark years. The statistically significant correlation coefficients of each combination are used to analyze the relationships

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[10] In actuality, although $\sum_{j=1}^{J} IECBW_j = J$, $\sum_{j=1}^{J} ECBW_j$ may not equal J exactly, due to round-off differences. For simplicity of exposition, however, we use the same notation for both.

between transportation and communications. With respect to the significance, we take a p-value less than or equal to 0.2 as indicating a statistically significant relationship. Although this is a more relaxed criterion than usual, it is still within the bounds of acceptable practice. For example, in the context of estimating the coefficients of discrete choice models, a t-statistic cutoff of 1.0 (in magnitude) or higher has been recommended (Horowitz *et al. 1*986), which roughly corresponds to a p-value of 0.3. In the context of ordinary least squares regression, it is noted that a t-statistic of 1.0 corresponds to the breakeven point at which the addition or deletion of a variable with that t-value does not change the adjusted R^2 of the model (Greene 2003). Thus, our standard of 0.2 still gives an overwhelming (80%) probability of being right when the null hypothesis of no correlation is rejected, and allows us more readily to see broad patterns in the data. As shown in Table 2, using a more conventional 0.1 standard does not change the qualitative nature of the results.

5. Results

Figure 3 exhibits the 100 correlation coefficients based on the direct and total requirements tables (five pairs for each of 10 benchmark years, for direct and total), together with their significance values. Table 2 summarizes the numbers of significant positive and negative correlation coefficients under the 0.2 and 0.1 standards of significance. Interestingly, Table 2 leaves the impression that the dominant impact is substitution (with the manufacturing pair constituting a notable exception), while Figure 3 shows that *in recent years* for *all* pairs, complementarity is the most frequent outcome (when the coefficient is significant at all). We discuss each set of results in turn.

[Figure 3 and Table 2 go about here]

5.1 Direct Analysis

Turning first to the correlation analysis using the direct coefficients, we immediately see complementarity almost across the board for the manufacturing pair (10×11). We see mostly substitution for the utilities pair (13×14) and for the transportation utilities and communications manufacturing pair (13×11). Correlations for the other two pairs (transportation manufacturing and communications utilities 10×14; and the "all" pair, 30×31) appear to be fluctuating around zero for most of the study period. What is striking about all four of the latter pairs, however, is that the patterns switch from negative (substitution) to positive (complementarity) between 1982 and 1987, and remain either positive or close to zero for the rest of the series. Although the two final correlations (1992 and 1997) are usually negligible, for the utilities pair (13×14), transportation utilities and communications manufacturing pair (13×11), and "all" pair (30×31), the observation in 1987 marks the first positive (and strongly significant) correlation in the entire series (following seven that are either significantly negative or essentially zero). The picture for the transportation manufacturing and communications utilities pair (10×14) is slightly more complex (with a significantly positive correlation in 1963 as well as in the final two benchmark years), but shows a similar pattern in which 1987 has the first positive and significant correlation following a string of (four) negative or zero values.

5.2 Total Analysis

With respect to the total coefficients, we observe basically two different patterns in the correlations across time. The first pattern consists of positive correlation coefficients across all 10 benchmark years (1947-1997) – that is, the relationship is uniformly complementarity – which is exhibited by the manufacturing pair (10×11). Based on our standard of significance (0.2), those correlations are statistically significant in eight out of the 10 periods (the exceptions being years 1947 and 1982). The second pattern consists of a run of negative correlation coefficients followed by a run of positive ones (i.e. a change from substitution to complementarity), and is exhibited by the remaining four pairs: transportation manufacturing and communications utilities (10×14), transportation utilities and communications manufacturing (13×11), the utilities pair (13×14), and transportation and communications overall (30×31).

More specifically, there are two types of sub-patterns among these four pairs: the 13×11 pair shows one such sub-pattern, and the remaining three pairs show the other. For the transportation utilities and communications manufacturing pair (13×11), the sign change occurs between 1967 and 1972, and quite dramatically: from significant negative in 1967 (-0.319, with p = 0.006) – that is, substitution – to significant positive in 1972 (0.339, with p = 0.004) – that is, complementarity. Although correlations in the following two benchmark years (1977 and 1982) remain positive, they are insignificant. But the positive correlations for the final three benchmark years show increasing magnitudes and significance each year.

In the remaining sub-pattern, the sign change occurs between 1982 and 1987 (giving seven benchmark years of substitution, followed by three periods of complementarity), for transportation manufacturing and communications utilities (10×14), the utilities pair (13×14), and transportation and communications overall (30×31). Although many of the coefficients are not statistically significant, and in particular none of those in the complementarity run are significant for 10×14 and 13×14, the consistency of the sign pattern both within and across pairs suggests that the pattern is meaningful, and not just reflecting random fluctuation around zero.

The pattern for the transportation and communications overall pair (30×31) is, loosely speaking, a composite of those for the other four pairs. Since those four pairs often show both substitution and complementarity effects in any given benchmark year, it is not surprising that they tend to cancel out in the composite, with the result that half of the correlations for the overall pair are insignificant. Starting in 1977, we see a significant negative correlation, followed by an insignificant correlation in 1982 at the switchover point to the significant positive ones in the final three periods. The latter result is not surprising in view of the fact that all four of the constituent patterns exhibit positive correlations (albeit significant only for two of the four pairs) for those final three periods.

Thus, the results for the total coefficients bear some rough similarities to the results using the direct coefficients. In the total case, however, three pairs (10×11 13×11, and 30×31) out of five present strongly positive and statistically significant correlations for the last three periods (and the other two pairs present positive but insignificant results for the same periods). Thus, in recent times we tend to observe stronger complementarity between communications and transportation based on the total requirements for these industry outputs, compared to the direct requirements only. [11]

[11] As mentioned in footnote 9 describing the transportation satellite accounts (TSAs), we also conducted the correlation analyses using the direct and total TSAs of 1992. Comparing the direct results using the TSAs to our results using the benchmark accounts, we see stronger complementarity for the TSAs, with more significant values for the "all" pair (30×31). The transportation utilities and communications manufacturing pair (13×11) shows a sign change from negative to positive (though small in magnitude in both cases), and the utilities pair (13×14) exhibits an increased magnitude of correlation and significance level (p = .114) – showing stronger complementarity. For the remaining two pairs (10×11 and 10×14), the results from the benchmark I-O accounts and the TSAs show similar complementarity (though slightly weaker for the TSAs). With respect to the total results using the TSAs, the relationship is uniformly complementarity across all pairs, with correlations that are quite similar to those of the

6. Conclusions and directions for further research

This study analyzed the relationships between transportation and communications as commodity inputs for each U.S. industry, and as industrial outputs to the final end-user demand for U.S. commodities, using input-output analysis (Leontief 1936). We used the direct and total coefficients matrices in the input-output accounts, where the total matrix takes into account not only outputs that are directly required by a given commodity, but also those that are indirectly required through their role in producing other outputs to a given commodity. We produced Spearman correlations between transportation and communications for each of 10 benchmark years (1947, 1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, and 1997), and we compared results across time based on five sets of correlations between transportation and communications (manufacturing, utilities, and total). To the address the problem of the lack of proper weighting noted by Saunders *et al.* (1994), we applied economic contribution-based weights[12] in computing the correlations, so that each industry (for the direct analysis) and commodity (for the total

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benchmark I-O accounts for the three pairs 10×11, 10×14, and 30×31; a bit lower for the 13×11 pair; and a bit higher for the 13×14 pair. The specific values are listed here, where the first number of each pair is the correlation and the second is the significance value: i) Direct: (10×11: 0.115, 0.283) (10×14: 0.129, 0.227) (13×11: 0.082, 0.442) (13×14: 0.169, 0.114) (30×31: 0.111, 0.300); ii) Total: (10×11: 0.259, 0.014) (10×14: 0.062, 0.564) (13×11: 0.190, 0.075) (13×14: 0.179, 0.093) (30×31: 0.158, 0.139). A reviewer suggested that the benchmark results might underestimate a complementarity effect, due to the omission of in-house transportation expenditures from the transportation utilities category. That is clearly true for the direct results, where the two correlations involving transportation utilities (category #13, the one most directly affected by the separate identification of in-house transportation) increase the most for the TSAs compared to the benchmark accounts. The total results are more mixed, but in any case the qualitative finding of the predominance of complementarity in 1992 is similar for both sets of accounts.

[12] The results are substantively different for the unweighted correlation analysis, more strongly supporting a substitution relationship. Specifically, there are a few more significant negative correlations (18) in the unweighted analysis than in the weighted analysis (15), and considerably fewer significant positive correlations (6) in the unweighted analysis than in the weighted analysis (15). In the unweighted analysis, the correlations for the 10x14 13x14, and 30x31 pairs are all negative or essentially zero, and for the 13x11 pair, only the final-year (1997) correlation is positive (and significant). For the 10x11 pair, however, five of the 10 correlations are significantly positive (the final year and the four benchmark years within 1958-1972), and only one (1982) is significantly negative. So the dominant complementarity between transportation and communications manufacturing is a robust result, occurring for both weighted and unweighted analyses of our data as well as in Plaut's analysis of similar categories.

For the rest, we believe that the weighted results are more credible, since they more appropriately reflect the contribution of each commodity to overall economic output. The reversal in dominant direction of correlation between the two results suggests that smaller industries (which receive weight equal to larger industries in the unweighted results) have a greater tendency to use transportation and communications as substitutes than do larger industries. To the extent that smaller *industry sectors* tend to have smaller *firms*, one explanation might be that smaller firms are more resource-constrained and also more institutionally nimble than larger ones, so that they are both more motivated to seek, and better able to adopt, the substitution of communications for travel as a cost-saving measure. The correlation between industry size (measured by economic contribution) and firm size within industry is in the expected direction (larger industry sectors tend to have larger firms), though not statistically significant.

analysis) was weighted proportionally to its contribution to total industrial outputs and commodity demands, respectively.

We found a mix of complementary and substitutive relationships among both direct and total results over the study period, as shown in Figure 3 and Table 2. In the analysis using the direct coefficients, however, there are intriguing indications of a possible structural change from substitution to complementarity for the utilities pair (13×14), transportation utilities and communications manufacturing pair (13×11), and "all" pair (30×31), beginning around 1987 in the analysis using the direct coefficients. With respect to the analysis using the total coefficients, we observed two temporal patterns among the five pairs of correlations – one showing complementarity across all 10 benchmark years (the manufacturing pair) and one showing a change of sign from substitution to complementarity (the remaining four pairs). This sign change occurred from 1967 to 1972 for the transportation utilities and communications manufacturing pair, and between 1982 and 1987 for the other three pairs. Thus, the most recent indications for all five sets of total coefficients are of complementarity. Although (as discussed in Section 1 and Table 1) we can speculate on some potential reasons for these structural changes in industrial relationships between communications and transportation (e.g. ICT facilitating decentralization at scales from local to global, the adoption of new ICT products and services such as JIT, EDI, GPS, RFID, and so on), more investigation is needed to determine which are the most plausible.

There are two main limitations of this study. First, as Saunders *et al.* (1994) point out, input coefficients are based on monetary values (dollars of input) rather than on activity levels *per se* (e.g. vehicle-miles traveled, or hours of Internet connection). Thus, the relationships observed using a monetary basis may differ substantially from those based on measures of actual activity. For example, requiring $x of output from industry *i* (say transportation) to meet one dollar of the final end-user demand for commodity *j*, does not say anything directly about the level of activity (say vehicle-miles traveled) involved for industry *i*. The interest of transportation planners, however, often lies more in measures of actual transportation activity (e.g. physical traffic flows on the network) than in economic measures. Since the price per unit of activity changes over time, just considering monetary expenditures can be misleading. For example, if the unit price of communications is falling relative to that of transportation, if an industry spends the same amounts of money on communications and transportation inputs over time, that industry would be acquiring gradually higher quantities of communications (on an activity-unit basis) than of transportation. On the other hand, as mentioned in the Introduction, Choo and Mokhtarian (2005, 2007) have investigated the aggregate relationships between telecommunications and travel activities (finding clear evidence that complementarity is the dominant effect). Given that, it is also valuable to explore the relationships between transportation and communications from a macroeconomic point of view, since monetary flows are also of interest, to economists and others.

Second, the Spearman correlation is just a measure of association, and does not identify true causality. In other words, just knowing that the amounts of communications and transportation outputs required for final end-user demand tend to be high or low together, does not address whether one actually *causes* the need for the other, or whether there is some third variable operating more or less separately on both. Further, since the analysis for each benchmark year is cross-sectional, we are only capturing patterns of relationships across industries – we do not really know (for example) how the use of communications would change for a *given* industry if its use of transportation increased. In any case, though, examining such relationships is of interest, and significant correlations can be at least a precursor to establishing causality. Furthermore, since, as we have seen (Table 1), there are a number of ways in which a causal relationship could conceivably occur, we can expect the observed relationships to have at least some causal foundations. Hence, despite these limitations, we are convinced that this study provides useful insight into the changing relationships between communications and transportation in U.S. industry. In particular, these data suggest that it is not realistic in modern times to expect communications to substitute for travel, at least in the industrial context, which constitutes a sizable proportion of the total demand for communications and transportation.

Despite these limitations, there are several rewarding directions for further research. First, it is clearly critical to incorporate the I-O accounts for the year 2002 as soon as they become available. This study used the benchmark I-O data from 1947 to 1997, the latest year available so far. Extending the analysis to the benchmark data for 2002 will help us determine whether complementarity remains the dominant relationship, whether there may be a cyclical shift from complementarity back to substitution, or whether in some cases there is random fluctuation around zero correlation (which, as noted before, may in fact reflect the net outcome of nearly equal substitution and complementarity effects). Second, our direct analysis (portions available in Lee and Mokhtarian 2004 and not presented here for brevity) found that results vary by level of disaggregation, so it would be beneficial to analyze the most disaggregate I-O accounts available. This study used the 79-134 industry categories as the most disaggregate classification that is available for all ten benchmark years (1947 through 1997). However, even more detailed data sets, which include about 500 industry categories, are available on the BEA website as electronic files (text version) from 1963 onward. Those data sets might allow us to analyze relationships more precisely than in this study, by further reducing the ecological errors caused by category aggregation. Third, it would be beneficial to continue to include in-house as well as for-hire transportation services in our definition of transportation utilities, if the transportation satellite accounts were to be maintained over time (see footnotes 9 and 11). Further, this study could be extended to distinguish between passenger and freight transportation services, if proposed efforts to make that distinction were to be accomplished (U.S. DOT 1999). The results would provide a more complete picture with respect to the relationships between transportation and communications.

Finally, to move beyond the currently cross-sectional analysis as discussed above, it would be of interest to analyze industry- and commodity-specific correlations taken across time (underway in Lee, in progress), rather than the time-specific correlations taken across industries and commodities that were the subject of the present paper. It is possible to calculate Spearman correlations across time for each industry and commodity in the direct and total coefficients matrices, respectively, i.e. correlations over t between A_{Tjt} and A_{Cjt} (using the direct coefficients matrix), or between λ_{Tjt} and λ_{Cjt} (using the total coefficients matrix) for each j. In analyzing these industry- and commodity-specific correlations, a price index to obtain constant dollars (e.g. the Producer Price Index) should be applied to each year because the input-output coefficients are developed based on current monetary values[13]. Converting input-output coefficients from "current" dollars to "constant" ones is important because using current dollars could mask substantial changes over time in the relative buying power for each input. The results would show how the relationships between transportation and communications differ across industries and commodities.

[13] The ideal approach in analyzing industry-specific correlations across time would be to apply an industry-specific price index to each I-O coefficient. Since the PPI (data available in Bureau of Labor Statistics in U.S. Department of Labor, http://www.bls.gov/ppi/home.htm, last accessed on June 3, 2007) provides indices that can be applied for various industry categories (i.e. for both i and j), it could potentially be used to convert current dollars into constant ones.

ACKNOWLEDGEMENTS

This study was partly funded by the University of California Transportation Center. Comments by Arpad Horvath and two anonymous reviewers helped improve this paper.

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Table 1. Examples of Potential Relationships (Substitution and Complementarity) between Transportation and Communications, across All Industries

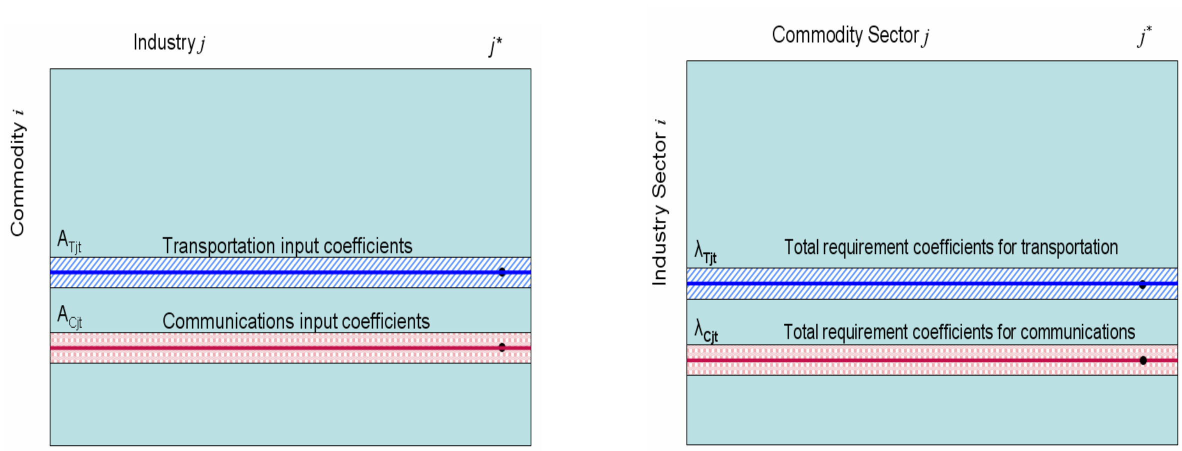
Impacts on / Examples	Transportation		Communications	
	Manufacturing	**Utilities**	**Manufacturing**	**Utilities**
Substitution				
Fax, email replacing physical delivery of documents	Less gasoline	Less use of delivery services	More fax equipment & computers	More use of phone & ICT services
Telephone, videoconferencing replacing physical passenger travel	Less gasoline, fewer company cars	Less air travel	More videoconferencing and network equipment	More use of phone & ICT services
Newspaper contents transmitted by satellite and printed locally rather than physically shipped long distances	Less gasoline, smaller company fleets	Less use of freight transporters	More computers, satellites	More use of satellite and other network services
Remote sensing devices replacing human data collection	Less gasoline		More remote sensing terminals, network equipment	More use of communications services
Information-sharing enabled by ICT permitting more freight load consolidation and efficient routing	Less gasoline, fewer delivery vehicles	Less use of delivery services	More computers, network equipment	More use of communications services
Complementarity				
ICT permitting decentralization of organizations, increasing travel among dispersed sites	More gasoline, more transportation vehicles	More use of transport services	More ICT equipment	More use of communication services
Increasingly global markets involving both more international business travel and more communications	More gasoline, airplanes	More use of air transport services	More ICT equipment	More use of communication services
Global supply chains requiring components produced from around the world	More gasoline	More use of ground, air, and marine transport	More phone, fax, and computer equipment	More use of phone and Internet services
Establishing and operating factory in developing country where labor is cheaper		More use of transport (air or marine) services	More phone, fax, and communications equipment	More use of phone and Internet services
Increased demand for "just-in-time" deliveries made possible by ICTs results in smaller loads and more frequent deliveries	More gasoline	More use of delivery services		More use of ICT services
Increased efficiency permitted by ICTs frees time for more business travel	More gasoline	More air travel, freight transport services needed as business expands	More communications equipment needed as business expands	More use of ICT services as business expands
ICTs improve the operations efficiency of the transportation network, decreasing the effective cost of travel & thus increasing its demand	More gasoline, transportation vehicles	More use of transport services	More ICT equipment	More use of ICT services

Table 2. Numbers of Significant (p=0.2 and p=0.1) Positive and Negative Spearman Correlations

Category Pairs		Number of Significant Correlations (out of 10)			
		Direct		Total	
		p=0.2	p=0.1	p=0.2	p=0.1
10 (TM) × 11 (CM)	+	7	5	8	7
	–	0	0	0	0
10 (TM) × 14 (CU)	+	4	1	0	0
	–	0	0	6	4
13 (TU) × 11 (CM)	+	1	1	4	4
	–	6	4	3	2
13 (TU) × 14 (CU)	+	1	1	0	0
	–	6	5	4	3
30 (AT) × 31 (AC)	+	1	1	3	1
	–	3	1	2	1

Notes: 10 (TM): Transportation Manufacturing; 11 (CM): Communications Manufacturing; 13 (TU): Transportation Utilities; 14 (CU): Communications Utilities; 30 (AT): All Transportation; 31 (AC): All Communications. Positive correlations denote complementarity; negative ones denote substitution. Number of industry observations (Direct): N=82 for 1947 and 1958; N=83 for 1963 and 1967; N=79 for 1972, 1977, and 1982; N=94 for 1987 and 1992; N=131 for 1997. Number of commodity observations (Total): N=82 for 1947, 1958, 1963, and 1967; N=79 for 1972, 1977, and 1982; N=97 for 1987 and 1992; N=134 for 1997.

Figure 1. Schematic Showing the Cross-Sectional Correlation between Transportation and Communications across Industries (Direct) or Commodities (Total) for Year t



a. Direct Coefficients b. Total Coefficients

Figure 2. Classification of Industries in the Input-Output Accounts

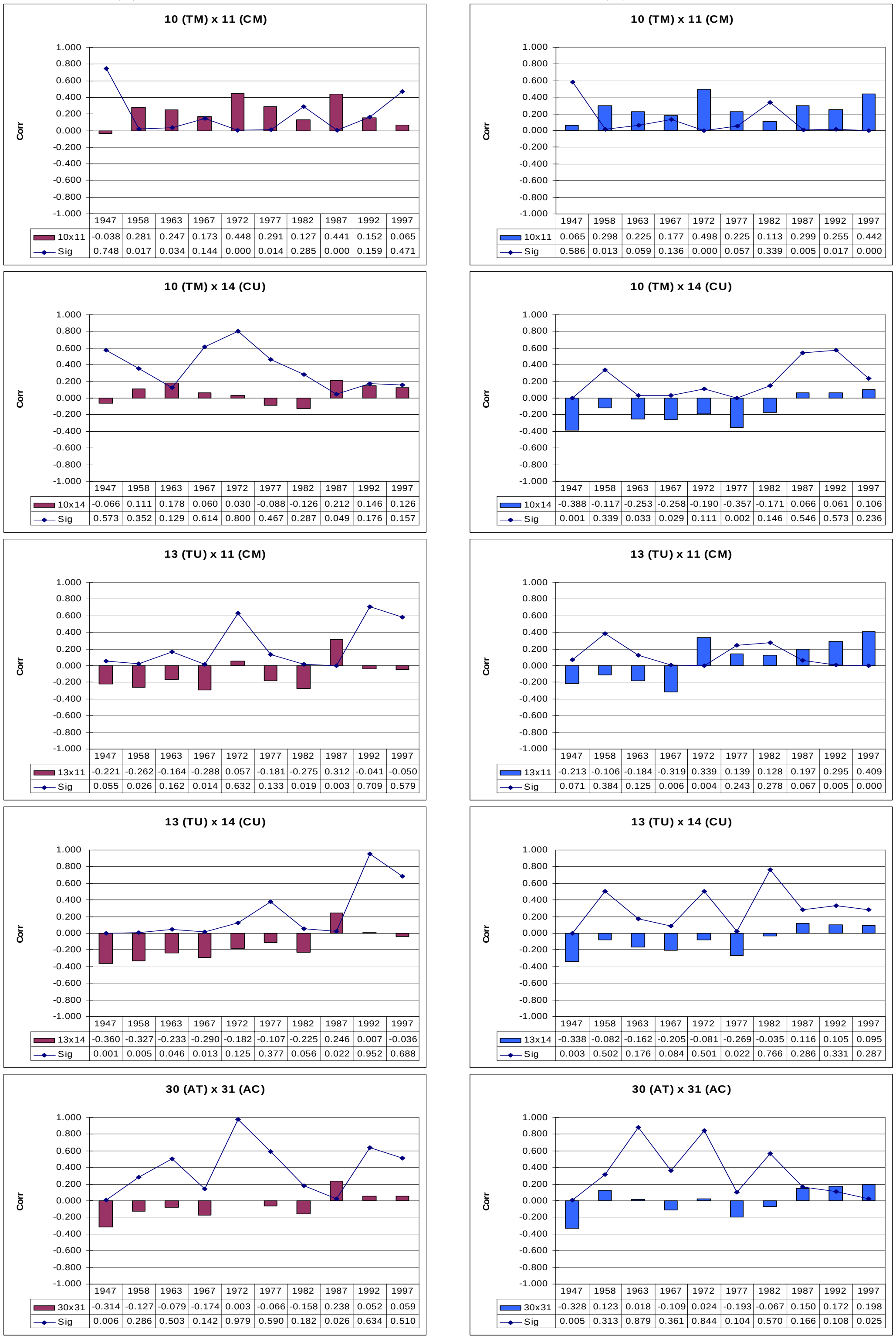
Study #	Classification	1947 – 1982	1987 and 1992	1997
1	Agriculture, forestry, and fisheries			
2	Mining			
3	Construction			
4	All manufacturing	10+11+12	10+11+12	10+11+12
5	All transportation, communications, and utilities	13+14+15	13+14+15	13+14+15
6	Wholesale and retail trade			
7	Finance, insurance, and real estate			
8	Services			
9	Special industries			
10	All transportation manufacturing	(16+17)+18+19+20	16+17+18+19+20	16+17+18+19+20
11	All communications manufacturing	21+22	21+22	21+22
12	Manufacturing except transportation & communications			
13	All transportation utilities	23+24+25+26+27	23+24+25+26+27	23A+23B+24A+24B+25 +26+27A+27B+27C+27D
14	All communications utilities	28+29	28+29	28+29A+29B
15	Utilities except transportation & communications utilities			

Study #	BEA #	(1) 1947 – 1982 Benchmark
16+17	59	Motor vehicles and equipment
18	60	Aircraft and parts
19	61	Other transportation equipment
20	31	Petroleum refining and related products
21	51	Computer and office equipment
22	56	Audio, video, and communication equipment
23 – 27	65	Transportation and warehousing
28	66	Communications, except radio and TV
29	67	Radio and TV broadcasting
30	All transportations manufacturing and utilities	10+13
31	All communications manufacturing and utilities	11+14

Figure 2. — Continued

Study #	BEA #	(2) 1987 and 1992 Benchmark	Study #	BEA #	(3) 1997 Benchmark
16	59A	Motor vehicles (passenger cars and trucks)	16	3361	Motor vehicle manufacturing
17	59B	Truck and bus bodies, trailers, and motor vehicles parts	17	336A	Motor vehicle body, trailer, and parts manufacturing
18	60	Aircraft and parts	18	3364	Aerospace product and parts manufacturing
19	61	Other transportation equipment	19	336B	Other transportation equipment manufacturing
20	31	Petroleum refining and related products	20	3240	Petroleum and coal products manufacturing
21	51	Computer and office equipment	21	3341	Computer and peripheral equipment manufacturing
22	56	Audio, video, and communication equipment	22	334A	Audio, video, and communications equipment manufacturing
23	65A	Railroads and related services; passenger ground transportation	23A	4820	Rail transportation
			23B	4850	Transit and ground passenger transportation
24	65B	Motor freight transportation and warehousing	24A	4840	Trucking transportation
			24B	4930	Warehousing and storage
25	65C	Water transportation	25	4830	Water transportation
26	65D	Air transportation	26	4810	Air transportation
27	65E	Pipelines, freight forwarders, and related services	27A	4860	Pipeline transportation
			27B	48A0	Scenic and sightseeing transportation and support activities for transportation
			27C	4920	Couriers and messengers
			27D	5615	Travel arrangement and reservation services
28	66	Communications, except radio and TV	28	5133	Telecommunications
29	67	Radio and TV broadcasting	29A	5131	Radio and television broadcasting
			29B	5132	Cable networks and program distribution
30	All transportations manufacturing and utilities	10+13	30	All transportations manufacturing and utilities	10+13
31	All communications manufacturing and utilities	11+14	31	All communications manufacturing and utilities	11+14

Figure 3. Spearman Correlations from Direct and Total Coefficients Matrices 1947-1997 Benchmark Years



(a) Direct Results

10 (TM) x 11 (CM)

	1947	1958	1963	1967	1972	1977	1982	1987	1992	1997
10x11	-0.038	0.281	0.247	0.173	0.448	0.291	0.127	0.441	0.152	0.065
Sig	0.748	0.017	0.034	0.144	0.000	0.014	0.285	0.000	0.159	0.471

10 (TM) x 14 (CU)

	1947	1958	1963	1967	1972	1977	1982	1987	1992	1997
10x14	-0.066	0.111	0.178	0.060	0.030	-0.088	-0.126	0.212	0.146	0.126
Sig	0.573	0.352	0.129	0.614	0.800	0.467	0.287	0.049	0.176	0.157

13 (TU) x 11 (CM)

	1947	1958	1963	1967	1972	1977	1982	1987	1992	1997
13x11	-0.221	-0.262	-0.164	-0.288	0.057	-0.181	-0.275	0.312	-0.041	-0.050
Sig	0.055	0.026	0.162	0.014	0.632	0.133	0.019	0.003	0.709	0.579

13 (TU) x 14 (CU)

	1947	1958	1963	1967	1972	1977	1982	1987	1992	1997
13x14	-0.360	-0.327	-0.233	-0.290	-0.182	-0.107	-0.225	0.246	0.007	-0.036
Sig	0.001	0.005	0.046	0.013	0.125	0.377	0.056	0.022	0.952	0.688

30 (AT) x 31 (AC)

	1947	1958	1963	1967	1972	1977	1982	1987	1992	1997
30x31	-0.314	-0.127	-0.079	-0.174	0.003	-0.066	-0.158	0.238	0.052	0.059
Sig	0.006	0.286	0.503	0.142	0.979	0.590	0.182	0.026	0.634	0.510

(b) Total Results

10 (TM) x 11 (CM)

	1947	1958	1963	1967	1972	1977	1982	1987	1992	1997
10x11	0.065	0.298	0.225	0.177	0.498	0.225	0.113	0.299	0.255	0.442
Sig	0.586	0.013	0.059	0.136	0.000	0.057	0.339	0.005	0.017	0.000

10 (TM) x 14 (CU)

	1947	1958	1963	1967	1972	1977	1982	1987	1992	1997
10x14	-0.388	-0.117	-0.253	-0.258	-0.190	-0.357	-0.171	0.066	0.061	0.106
Sig	0.001	0.339	0.033	0.029	0.111	0.002	0.146	0.546	0.573	0.236

13 (TU) x 11 (CM)

	1947	1958	1963	1967	1972	1977	1982	1987	1992	1997
13x11	-0.213	-0.106	-0.184	-0.319	0.339	0.139	0.128	0.197	0.295	0.409
Sig	0.071	0.384	0.125	0.006	0.004	0.243	0.278	0.067	0.005	0.000

13 (TU) x 14 (CU)

	1947	1958	1963	1967	1972	1977	1982	1987	1992	1997
13x14	-0.338	-0.082	-0.162	-0.205	-0.081	-0.269	-0.035	0.116	0.105	0.095
Sig	0.003	0.502	0.176	0.084	0.501	0.022	0.766	0.286	0.331	0.287

30 (AT) x 31 (AC)

	1947	1958	1963	1967	1972	1977	1982	1987	1992	1997
30x31	-0.328	0.123	0.018	-0.109	0.024	-0.193	-0.067	0.150	0.172	0.198
Sig	0.005	0.313	0.879	0.361	0.844	0.104	0.570	0.166	0.108	0.025

Notes: 10 (TM): Transportation Manufacturing; 11 (CM): Communications Manufacturing; 13 (TU): Transportation Utilities; 14 (CU): Communications Utilities; 30 (AT): All Transportation; 31 (AC): All Communications. See Table 3 notes for sample sizes.

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