# AN INPUT-OUTPUT ANALYSIS OF THE RELATIONSHIPS BETWEEN COMMUNICATIONS AND TRAVEL FOR INDUSTRY

**Final Report**


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## Overview

Numerous public policies have been promulgated on the assumption that telecommunications will be a useful trip reduction instrument. However, many scholars have suggested that the predominant effect of telecommunications may be complementarity – increasing travel. Although short-term, disaggregate studies of single applications such as telecommuting have tended to find a substitution effect, more comprehensive studies, on the aggregate scale, are needed. One of the few such studies used input-output analysis to examine relationships between transportation and communication input intensities across 44 industry classes in Europe for 1980, and found strong evidence of complementarity. The present study has applied a similar methodology to the input-output accounts for the US across multiple points in time.

Specifically, this study applied the input-output analysis technique developed by Leontief in 1936 to analyze the relationship between transportation and communications as industrial inputs in the U.S. Generally, input-output analysis offers a static view of the structural relationships, expressed purely in monetary terms, among the different sectors of an economy for a certain period of time. We analyzed correlations between transportation and communications using the input coefficients of transportation and communications in the input-output table (direct coefficients matrix). Positive correlation coefficients indicate complementarity: industries that require a lot of transportation inputs also tend to require a lot of communications inputs, and conversely. Negative correlation coefficients imply substitution.

Ten benchmark I-O accounts (between 1947 and 1997, inclusive) were collected, which are prepared using the most detailed data sources available, generally the economic censuses. Trying to find the best balance between highly disaggregated industry classifications (which may exhibit a lot of random noise that would obscure the pattern of interest) and highly aggregated ones (which contain such a small number of cases that it may also be hard to identify underlying relationships), we created four scenarios reflecting different levels of aggregation across sub-industries. Scenario 1 is the most disaggregate level (containing 79-131 categories, depending on year), while Scenario 4 is the most aggregate categorization, containing just the nine top-level industries. We analyzed correlations for five selected pairs of transportation and communications industry categories: the manufacturing pair (i.e., transportation manufacturing correlated with communications manufacturing), the utilities pair, the two manufacturing-utilities pairs, and the overall pair (all transportation manufacturing and utilities correlated with all communications manufacturing and utilities).

In this study the Spearman correlation is used, which is a nonparametric correlation measure. Since the input-output coefficients are not normally distributed, the Pearson correlation coefficients are not strictly appropriate. Using Spearman correlations, we conducted a cross-sectional analysis for each time period, and compared results across time based on the five sets of correlations between transportation and communications. Thus, 200 correlation coefficients in all are computed in this study (five sets for each of four scenarios for each of 10 benchmark years).

## Key Results

These 200 correlations are plotted in Figure ES-1, and summarized in Tables ES-1 & ES-2. These summaries exhibit several interesting patterns. Since Scenario 1 is the most disaggregate level available for all 10 benchmark years, and the other scenarios are aggregated to varying degrees, Scenario 1 is the scenario closest to the level of the individual actors (companies). With that in mind, concentrating on Scenario 1 demonstrates a pattern of predominant complementarity for the manufacturing pair (10×11) and substitution for the utilities pair (13×14). For the other pairs, we see complementarity between transportation manufacturing and communications utilities (10×14) and substitution between transportation utilities and communications manufacturing (13×11) as well as between transportation and communications overall (30×31), although the first and last of those results are somewhat weakly based on only four significant correlations out of 10.

Closer scrutiny of Scenario 1 in Figure ES-1 reveals another striking pattern. For all five comparison pairs, the 1987 benchmark year marks a break of some kind with the preceding benchmark year. For the manufacturing pair (10×11), the 1987 correlation is substantially higher than those of the adjacent benchmark years, and appears to mimic the peak-and-decline cycle observed to start 15 years earlier in 1972. For the utilities pair (13×14), transportation utilities – communications manufacturing pair (13×11), and "all" pair (30×31), 1987 marks the first positive (and strongly significant) correlation in the entire series (following seven that are either significant negative or essentially zero), with the remaining two correlations essentially zero. The picture for the transportation manufacturing – 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 ones.

Whether the positive spikes at 1987 represent a long-term structural shift from substitution to complementarity or an anomalous year in a pattern that is returning to negative (or zero) is difficult to tell from the limited information in the following years. Certainly, it will be critical to examine the results for the 2002 benchmark year once they become available. For now, it must simply be stated that the dominant findings of substitution for the latter three of the five category pairs for Scenario 1 may be a historical artifact that is changing, since the single significant positive correlation in each of those three cases in the most recent year (1987) for which a coefficient in the series is significant.

This study has two main limitations. First, the relationships observed using a monetary basis may differ substantially from those based on measures of actual activity (such as volumes of communication or distance traveled). Second, we are identifying associations between communications and transportation inputs demanded, but that does not say anything about whether one actually causes the need for the other. However, there are a number of ways in which a causal relationship could plausibly occur (several examples are provided in the full report), so it is reasonable to expect the observed associations to have at least some causal foundation. Thus, despite these limitations, we believe the study offers a more informed view of the extent to which it is realistic to expect telecommunications to substitute for travel, at least in the industrial context, which constitutes a sizable proportion of the total demand for telecommunications and transportation. It further offers provocative insight into possible structural changes in the economic relationships between transportation and communications inputs to industry, beginning to be noticeable around 1987.

There are a number of fruitful directions for further research, including replication using the total input coefficients (accounting for an industry's indirect demand for communication and transportation, through its demand for other inputs that require them), using I-O accounts for the year 2002 as soon as they become available, using the even more disaggregate I-O accounts available electronically from 1982 onward, and analyzing industry specific correlations taken over time.

**Table ES- 1. Definition of Each Category**

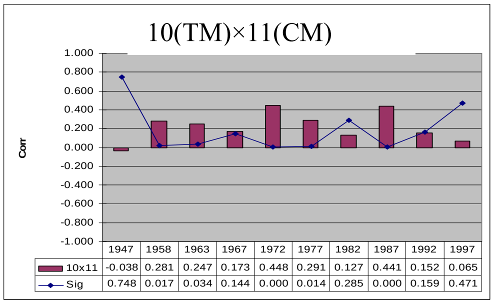
| No. | Definition |
|---|---|
| **10** | Transportation Manufacturing |
| **11** | Communications Manufacturing |
| **13** | Transportation Utilities |
| **14** | Communications Utilities |
| **30** | All Transportation Manufacturing and Utilities (10+13) |
| **31** | All Communications Manufacturing and Utilities (11+14) |

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

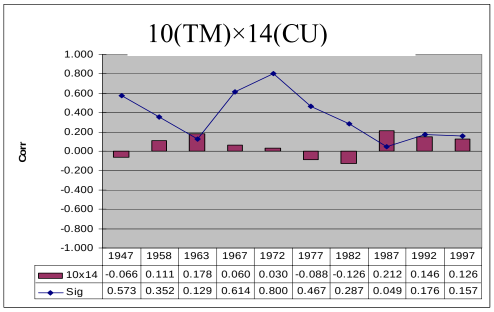
| Category Pairs | | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Total |
|---|---|---|---|---|---|---|
| **10×11** | + | 7 | 5 | 8 | 7 | 27 |
| | – | 0 | 1 | 0 | 0 | 1 |
| **10×14** | + | 4 | 0 | 0 | 0 | 4 |
| | – | 0 | 2 | 3 | 1 | 6 |
| **13×11** | + | 1 | 3 | 3 | 5 | 12 |
| | – | 6 | 1 | 0 | 0 | 7 |
| **13×14** | + | 1 | 0 | 0 | 0 | 1 |
| | – | 6 | 7 | 8 | 3 | 24 |
| **30×31** | + | 1 | 1 | 2 | 1 | 5 |
| | – | 3 | 3 | 3 | 0 | 9 |

Notes: Scenario 1: The most disaggregate level (79-131 categories); Scenario 2: More aggregate level (18-29 categories); Scenario 3: Next most aggregate level (13 categories); Scenario 4: The most aggregate level (9 top-level categories).

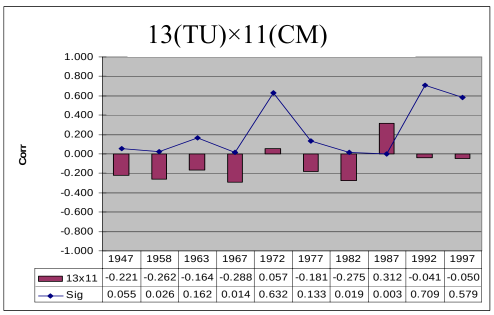
**Figure ES- 1. Spearman Correlations from Direct Coefficients Matrix, 1947-1997 Benchmark Years**



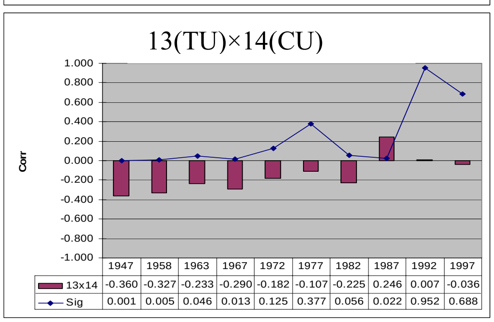

| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10x11 | -0.038 | 0.281 | 0.247 | 0.173 | 0.448 | 0.291 | 0.127 | 0.441 | 0.152 | 0.065 |
| Sig | 0.748 | 0.017 | 0.034 | 0.144 | 0.000 | 0.014 | 0.285 | 0.000 | 0.159 | 0.471 |



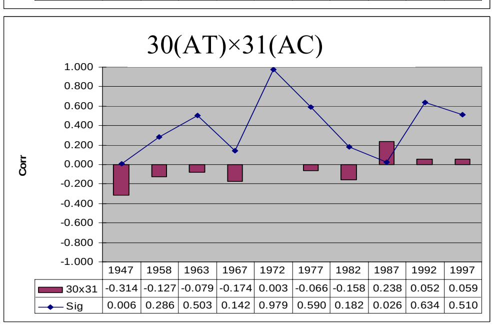

| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10x14 | -0.066 | 0.111 | 0.178 | 0.060 | 0.030 | -0.088 | -0.126 | 0.212 | 0.146 | 0.126 |
| Sig | 0.573 | 0.352 | 0.129 | 0.614 | 0.800 | 0.467 | 0.287 | 0.049 | 0.176 | 0.157 |




| | 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 |

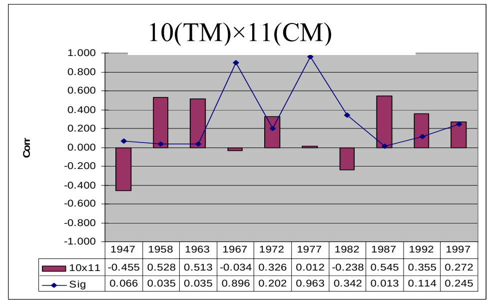



| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 13x14 | -0.360 | -0.327 | -0.233 | -0.290 | -0.182 | -0.107 | -0.225 | 0.246 | 0.007 | -0.036 |
| Sig | 0.001 | 0.005 | 0.046 | 0.013 | 0.125 | 0.377 | 0.056 | 0.022 | 0.952 | 0.688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

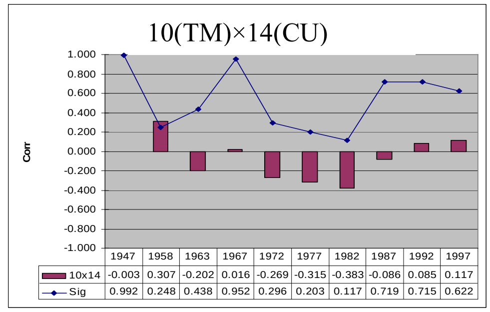



| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 30x31 | -0.314 | -0.127 | -0.079 | -0.174 | 0.003 | -0.066 | -0.158 | 0.238 | 0.052 | 0.059 |
| Sig | 0.006 | 0.286 | 0.503 | 0.142 | 0.979 | 0.590 | 0.182 | 0.026 | 0.634 | 0.510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

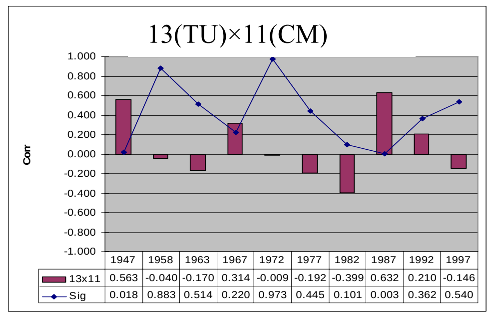
**a. Scenario 1: The Most Disaggregate Scenario (79-131 categories)**



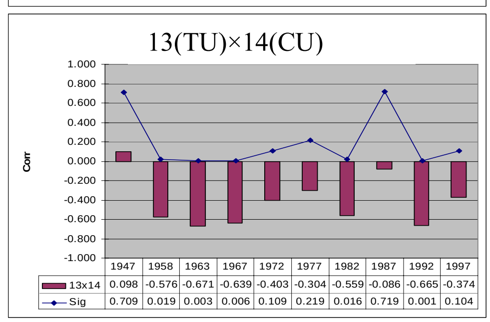

| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10x11 | -0.455 | 0.528 | 0.513 | -0.034 | 0.326 | 0.012 | -0.238 | 0.545 | 0.355 | 0.272 |
| Sig | 0.066 | 0.035 | 0.035 | 0.896 | 0.202 | 0.963 | 0.342 | 0.013 | 0.114 | 0.245 |



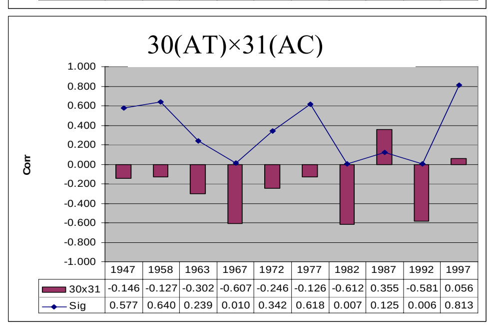

| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10x14 | -0.003 | 0.307 | -0.202 | 0.016 | -0.269 | -0.315 | -0.383 | -0.086 | 0.085 | 0.117 |
| Sig | 0.992 | 0.248 | 0.438 | 0.952 | 0.296 | 0.203 | 0.117 | 0.719 | 0.715 | 0.622 |




| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 13x11 | 0.563 | -0.040 | -0.170 | 0.314 | -0.009 | -0.192 | -0.399 | 0.632 | 0.210 | -0.146 |
| Sig | 0.018 | 0.883 | 0.514 | 0.220 | 0.973 | 0.445 | 0.101 | 0.003 | 0.362 | 0.540 |



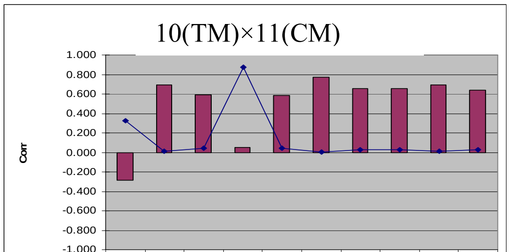

| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 13x14 | 0.098 | -0.576 | -0.671 | -0.639 | -0.403 | -0.304 | -0.559 | -0.086 | -0.665 | -0.374 |
| Sig | 0.709 | 0.019 | 0.003 | 0.006 | 0.109 | 0.219 | 0.016 | 0.719 | 0.001 | 0.104 |



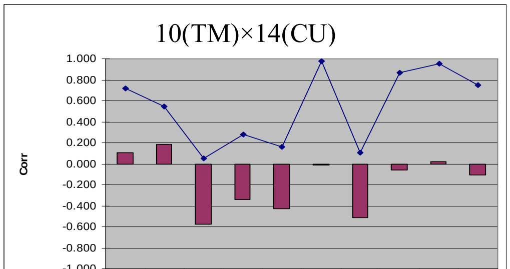

| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 30x31 | -0.146 | -0.127 | -0.302 | -0.607 | -0.246 | -0.126 | -0.612 | 0.355 | -0.581 | 0.056 |
| Sig | 0.577 | 0.640 | 0.239 | 0.010 | 0.342 | 0.618 | 0.007 | 0.125 | 0.006 | 0.813 |

**b. Scenario 2: More Aggregate Scenario (18-29 categories)**

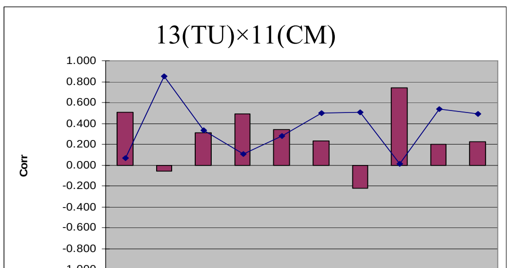
Note: TM(10): Transportation Manufacturing; CM(11): Communications Manufacturing; TU(13): Transportation Utilities CU(14): Communications Utilities; AT(30): All Transportation; CT(31): All Communications



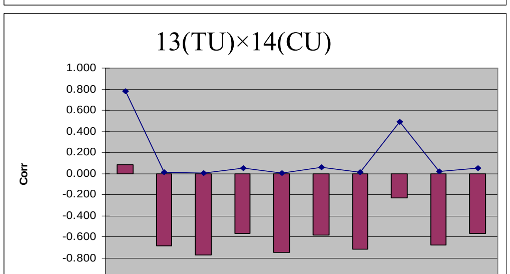

| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10x11 | -0.286 | 0.692 | 0.594 | 0.053 | 0.584 | 0.769 | 0.654 | 0.654 | 0.697 | 0.639 |
| Sig | 0.322 | 0.009 | 0.042 | 0.871 | 0.046 | 0.006 | 0.029 | 0.029 | 0.012 | 0.025 |



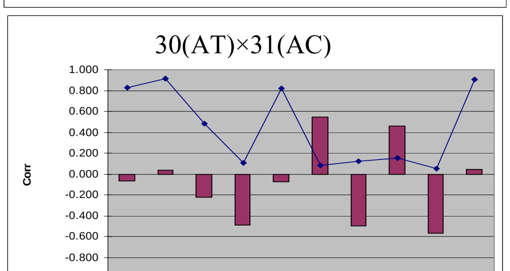

| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10x14 | 0.106 | 0.186 | -0.579 | -0.338 | -0.431 | -0.010 | -0.514 | -0.056 | 0.018 | -0.105 |
| Sig | 0.718 | 0.543 | 0.049 | 0.282 | 0.162 | 0.978 | 0.106 | 0.870 | 0.956 | 0.746 |




| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 13x11 | 0.507 | -0.058 | 0.308 | 0.489 | 0.343 | 0.231 | -0.224 | 0.738 | 0.199 | 0.220 |
| Sig | 0.064 | 0.850 | 0.330 | 0.107 | 0.275 | 0.495 | 0.507 | 0.009 | 0.536 | 0.492 |

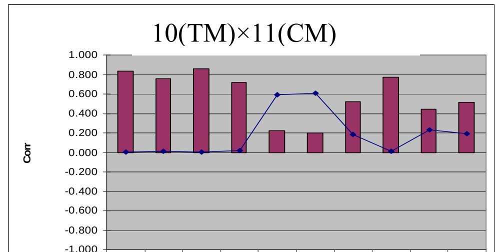



| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 13x14 | 0.083 | -0.686 | -0.774 | -0.571 | -0.752 | -0.587 | -0.720 | -0.234 | -0.675 | -0.567 |
| Sig | 0.778 | 0.010 | 0.003 | 0.052 | 0.005 | 0.058 | 0.013 | 0.489 | 0.016 | 0.055 |

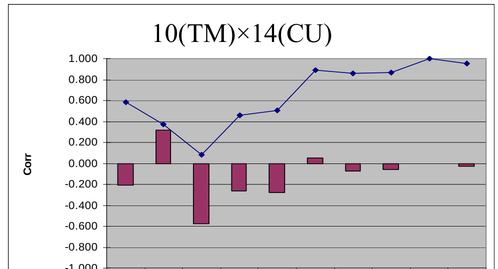



| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 30x31 | -0.065 | 0.035 | -0.226 | -0.489 | -0.073 | 0.548 | -0.495 | 0.458 | -0.567 | 0.040 |
| Sig | 0.827 | 0.910 | 0.481 | 0.107 | 0.822 | 0.081 | 0.121 | 0.157 | 0.055 | 0.902 |

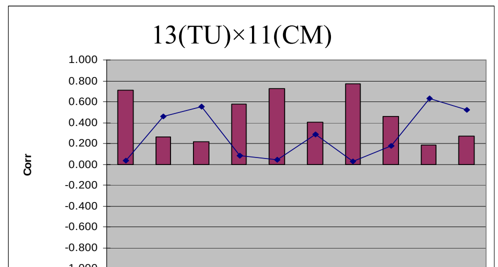
**c. Scenario 3: Next Most Aggregate Scenario (13 categories)**



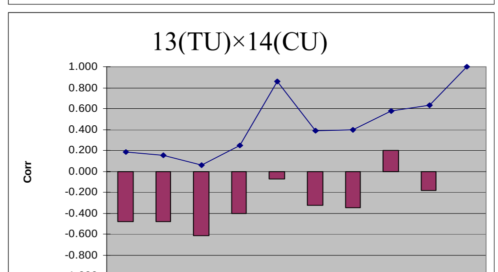

| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10x11 | 0.835 | 0.755 | 0.858 | 0.716 | 0.225 | 0.200 | 0.525 | 0.775 | 0.441 | 0.512 |
| Sig | 0.005 | 0.012 | 0.001 | 0.020 | 0.592 | 0.606 | 0.182 | 0.008 | 0.235 | 0.194 |



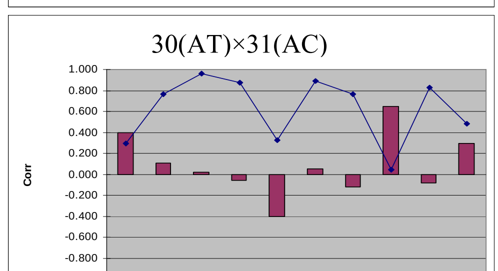

| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10x14 | -0.211 | 0.316 | -0.574 | -0.265 | -0.275 | 0.055 | -0.075 | -0.063 | 0.000 | -0.024 |
| Sig | 0.586 | 0.374 | 0.083 | 0.460 | 0.510 | 0.889 | 0.860 | 0.864 | 1.000 | 0.954 |




| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 13x11 | 0.706 | 0.265 | 0.213 | 0.574 | 0.725 | 0.400 | 0.775 | 0.463 | 0.186 | 0.268 |
| Sig | 0.033 | 0.460 | 0.555 | 0.083 | 0.042 | 0.286 | 0.024 | 0.178 | 0.631 | 0.521 |




| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 13x14 | -0.486 | -0.484 | -0.613 | -0.406 | -0.075 | -0.327 | -0.350 | 0.200 | -0.186 | 0.000 |
| Sig | 0.184 | 0.156 | 0.060 | 0.244 | 0.860 | 0.390 | 0.395 | 0.580 | 0.631 | 1.000 |




| | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|
| 30x31 | 0.394 | 0.110 | 0.019 | -0.058 | -0.400 | 0.055 | -0.125 | 0.650 | -0.085 | 0.293 |
| Sig | 0.293 | 0.763 | 0.958 | 0.873 | 0.326 | 0.889 | 0.768 | 0.042 | 0.828 | 0.482 |

**d. Scenario 4: The Most Aggregate Scenario (9 categories)**

Note: TM(10): Transportation Manufacturing; CM(11): Communications Manufacturing; TU(13): Transportation Utilities CU(14): Communications Utilities; AT(30): All Transportation; CT(31): All Communications

# CHAPTER 1. INTRODUCTION

Investigation of the relationship between telecommunications and travel has been a fertile area of research for many years. More than four decades ago, Owen (1962) focused on the potential of telecommunications to replace travel, and noted that "… with the development of telegraph, telephone, radio, and television, communications no longer depend on transportation and are often an effective substitute" (p. 412). This expectation ultimately led to the establishment of several telecommuting programs, and empirical evaluations of those programs (e.g., Hamer *et al*., 1991; Quaid and Lagerberg, 1992; Roads and Traffic Authority, 1995; Mokhtarian *et al*., 1995) seemed to support the substitution prospect. While empirical evidence for other telecommunications applications was far more scarce, it was similarly expected that teleconferencing, teleshopping, distance learning, and other such services would also replace travel. In the meantime, however, some scholars (e.g., Albertson, 1977; Salomon, 1985; Mokhtarian, 1990, 2002; Niles, 1994) 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. This effect could arise in two kinds of ways, which the literature (Salomon, 1986) labels enhancement and efficiency.

- Enhancement refers to a direct impact of one mode of communication (e.g., telecommunications) on the demand for another mode (e.g., travel). For example, the increasing ease of electronically obtaining information about interesting locations, activities, and people could stimulate the demand for travel to visit those locations or people and engage in those activities (Pierce, 1977; Gottman, 1983; Couclelis, 1999).
- Efficiency refers to the use of one mode (e.g., telecommunications) to improve the operation of another mode (e.g., the transportation network). The effect on demand is indirect in this case, by increasing the effective supply of transportation and hence, by lowering its (generalized) cost, making travel more attractive and thus increasing the demand for it.

Based partly on the favorable empirical results mentioned above, and partly on the optimism and opportunism endemic to public sector decision-making, a number of public policies have been promulgated on the assumption that telecommunications will be a useful trip reduction instrument (e.g., Gordon, 1992, 1993, 1996; Castaneda, 1999; Joice, 2000). However, it has been suggested (Mokhtarian and Meenakshisundaram, 1999; Mokhtarian, 2002) 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. Certainly, any plot of the aggregate amounts of communications and travel over time, at practically any geographic level (e.g., Grubler, 1989), illustrates that overall, they continue to rise together.

Given the favor with which telecommunications is viewed as a transportation demand management tool, it is important to better understand the nature of its relationship with travel, in order to determine whether the optimism about its substitution potential is misplaced. In particular, it seems vital to move beyond the small-scale evaluations of single applications such as telecommuting, to a more complete view of telecommunications activity in general. Such studies could be conducted at either the disaggregate or the aggregate level, and each approach has its advantages (Mokhtarian and Salomon, 2002): disaggregate studies have the potential to offer more insight into behavior-based causal relationships, whereas aggregate studies can offer a more comprehensive scope. The current study takes an aggregate approach.

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 have pairwise relationships of substitution. Noting that industry accounts for 2/3 of total expenditures on transportation and communications, Plaut (1997) utilized input-output analysis[1] to investigate the relationships between communications and transportation as inputs to 44 different industry groups (including communications and transportation themselves) for nine countries of the European Commission in the year 1980. For all nine countries, she found generally positive correlations across industries. That is, for the 44 industry groups overall, when communications inputs were high, transportation inputs also tended to be high, and conversely. She concluded that there was a complementary[2] relationship between communication and travel, at least for the industrial context.

Later, Plaut (1999) investigated the relationship between communications and transportation in 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. Therefore, both the number and content of industry categories corresponding to transportation and communications are not exactly the same across countries.

Thus, only one of these studies (Plaut, 1999) investigates (to some extent) the relationships for the case of the U.S., as part of an international comparison of Israel, Canada, the U.S. and Europe. However, the study analyzes only one year for the U.S., which is not specified. Further, with respect to the methodological approach, the study seems to be inconsistent (to some extent) in terms of comparing results across countries. For most countries, Plaut uses the Spearman correlation as the indicator of the relationship between transportation and communications inputs. The Spearman correlation is more appropriate than the more usual Pearson correlation because the Spearman correlation is a nonparametric measure. It compares the rank orders of the intensity of uses of both transportation and communications across industry branches, and makes no assumptions about the distribution of data, which is important since input-output coefficients are not normally distributed as use of the Pearson correlation requires. For the United States alone, however, the Pearson correlation is inexplicably used.

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[1] Input-output analysis was first developed by Leontief (1936), and is widely used in planning processes in many countries. It is also used to investigate interrelationships among industries, and is commonly employed at national as well as regional levels. This approach is explained more fully in Chapter 2.

[2] As Plaut points out, this is a use of the term that technically differs from its conventional definition in microeconomics, but one that is similar in concept: an increase in the demand for one good is associated with an increase in the demand for the complementary good.

The purpose of this study is to explore the aggregate relationships between transportation and communications as industrial inputs in the U.S., using input-output accounts provided by the Bureau of Economic Analysis (BEA) in the U.S. Department of Commerce, and to compare results across time as well as across various scenarios that are based on the level of aggregation.

This study extends Plaut's work in several important ways. First, this study analyzes U.S. input-output tables for ten points in time within the period from 1947 to 1997. The years comprise the ten benchmark years for the I-O accounts for the U.S. economy during that period. The benchmark I-O accounts, which are published by the U.S. Department of Commerce, provide comprehensive accounting of the production of goods and services of each industry and commodity (Lawson *et al.*, 2002). The benchmark I-O accounts are now published every five years, with some exceptions in the early years, i.e., 1947, 1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, and 1997.

The attention to the temporal dimension, an aspect not addressed by Plaut, enables us to explore how economy-wide correlations (that is, correlations of communication and transportation input intensities across all industries) change over time. It provides insight into how the expansion of information technologies over time might be affecting the relative needs for communications versus transportation as industrial inputs (in particular, the 1980 European, 1988 Israeli, 1991 Canadian, and presumably the United States data studied by Plaut predate considerable development in the telecommunications industry, which may be facilitating greater substitution for transportation or stimulating greater complementarity).

Second, this study examines 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. Specifically, interrelationships among six industry categories are analyzed in this study: (1) transportation manufacturing, (2) communications manufacturing, (3) transportation utilities, (4) communications utilities, (5) all transportation manufacturing and utilities (categories (1) + (3)), and (6) all communications manufacturing and utilities (categories (2) + (4)).

Third, the economic contribution-based weight (ECBW) is introduced in this study, which is applied to each I-O coefficient of the corresponding industry. That is, all I-O coefficients are weighted depending on the economic contribution of the output industry to the U.S. economy. Application of the ECBW results in more economically realistic relationships between transportation and communications, compared to the unweighted correlation which gives each output industry equal weight regardless of its size.

This report is organized as follows. Chapter 2 presents an introduction to input-output analysis and its application to this study. Chapter 3 discusses the data collection regarding I-O accounts and manipulation of the data for analyses. Chapter 4 outlines the methodological approach for this study. Chapter 5 presents some potential specific relationships between transportation and communications, the empirical findings of this study, and its main limitations. Finally, conclusions and potential further studies are discussed in Chapter 6.

# CHAPTER 2. INTRODUCTION TO INPUT-OUTPUT ANALYSIS AND ITS APPLICATION TO THIS STUDY

The first section of this chapter introduces the fundamental methodological concepts of input-output analysis, including the "direct coefficient matrix" and "total coefficient matrix". In Section 2.2, several studies involving I-O analysis are briefly reviewed. The application of input-output analysis to this study is described in Section 2.3, including the presentation of table templates that illustrate what we are analyzing in this study.

## *2.1 Concept of the Input-Output Methodology*

Input-output analysis was first introduced by Wassily Leontief (1936), and is widely used as a quantitative model for national and regional economic analysis. In general terms, input-output analysis offers a static view of the structural relationships among the different sectors of an economy (typically national, or regional) for a certain period of time, generally a year. It is emphasized that these relationships are expressed purely in monetary terms.

The input-output accounts consist of five basic tables: (i) make, (ii) use, (iii) commodity-by-industry direct requirements, (iv) commodity-by-commodity total requirements, and (v) industry-by-commodity total requirements. The ***make table*** (industry by commodity) presents the value in producers' prices of each commodity produced by each industry. The row total for industry i constitutes the monetary value of industry i's output across all commodities, and the column total constitutes the total value of the production of commodity j across all industries. The ***use table*** shows the value in producers' prices of each commodity used by each industry or by each final user. The ***commodity-by-industry direct requirements table*** provides the input coefficients (i.e., the fractional amount of a dollar) for each commodity that an industry requires to produce a dollar of output. The ***commodity-by-commodity total requirements table*** shows the monetary value of the input amounts of each commodity i that are directly and indirectly required to deliver a dollar of commodity j to final users. The column total constitutes the dollar value across all commodity outputs required to deliver a dollar of commodity j, and is referred to as the *total commodity output multiplier* (e.g., it may require $2.50 of all commodities added together to deliver $1 of commodity j to final users). Finally, the ***industry-by-commodity total requirements table*** presents input coefficients for the output from each industry i, which are directly and indirectly required to deliver a dollar of a commodity j to final users. The column total of this table constitutes the dollar value across all industry outputs required to deliver a dollar of commodity j, and is called the *total industry output multiplier*. Tables (iv) and (v) are similar, except that Table (iv) includes "non-comparable imports" that are not included in Table (v). Nevertheless, even though the output required to deliver a dollar of commodity to final users might include both imported and domestic commodities, the multipliers produced by both tables represent the output required as if all of the commodity were produced domestically. To the extent that commodities are imported, the multipliers will overstate the effect on the domestic economy of increasing the dollar-valued amounts of a given commodity delivered to final users.

The analysis in this study focuses on the direct coefficient matrix (commodity-by-industry), Table (iii). The direct coefficient matrix is derived from the following equation:

$$a_{ij} = \frac{X_{ij}}{X_j} \tag{2.1}$$

where $a_{ij}$ is the input coefficient of the direct coefficient matrix, $X_{ij}$ is the monetary value of inputs from sector *i* to 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 from sector *i* that is required to produce a dollar of gross output in sector *j*. The input coefficients explain the producing structure of each industry, which implies an interrelationship among industries.

There are several basic assumptions in the input-output model:

1) Industrial output is homogeneous. This implies that every good produced by a certain industry has no quality distinction, and is regarded as equal and homogeneous.
2) For all industries, returns to scale are constant. This means that if the output produced by a certain industry were to increase or decrease by x percent, the inputs required by that industry also rise or fall by the same percentage.
3) Fixed production-function processes. This implies that all companies within a certain industry produce goods or services in the same way, i.e., requiring the same proportions of each input.
4) The technological nature of the input-output relationships is uniform. This means that no technological improvement is generated at least during the analysis period.

Of course, each of these assumptions is a simplification of a more complex reality.

## *2.2 Review of Selected Input-Output Literature*

Many studies using I-O analysis in various fields have been implemented. More specifically, numerous studies have explored aspects of technological change using input-output analysis. However, the use of input-output methodological approaches in the transportation field is relatively limited. We focus mainly on those studies that address technological changes or have transportation applications.

After the groundbreaking contribution of Leontief (1936) in developing input-output methodologies, input-output tools have been widely utilized not only in planning processes (Sand, 1988; Szymer, 1986), but also in policy design (Baumol and Wolff, 1994). Further, the I-O model is used at the regional as well as the national level. Isard (1951) proposed the application of interregional and regional input-output analysis to reveal economic relations between and within two regions.

In the meantime, the basic I-O model was extended to the study of production technology in recent years. Studies in numerous fields have been conducted, such as the investment impact on productivity for the United Kingdom through the construction of the investment matrix (Gossling, 1975), and the impact of technological change (Miller *et al*., 1989; Leontief, 1986). Duchin (1989) examined structural change in the U.S. economy, and suggested that the dynamic input-output model can be a good approach for analyzing the future economic implications of technological change. Blair and Wyckoff (1989) noted structural changes in the U.S. economy resulting from changes in final demand. Kanemitsu and Ohnishi (1989) concluded that production costs and prices of goods have been reduced by technological change in the Japanese economy from 1970 to 1980. Leontief (1986) investigated the model's application to analysis of new patterns of technological change in the structure of the U.S. economy.

For the transportation industry in particular, Ferguson (1976) explored the inputs to the production of commercial air transportation in the U.S. in the years 1939 and 1947. The study investigated the correlations of other airline investments (other flight equipment (y); and property and equipment other than flight equipment (z)) with aircraft (x), and concluded there is a rigid complementary relation between aircraft (x) and other airline investments (y and z) since the coefficient of correlation in both cases is very high ($R_{x,y}$: 0.917, $R_{x,z}$: 0.911). Polenske (1974 and 1980) examined the transportation sector using I-O analysis. She conducted an interindustry I-O analysis to estimate the impact and economic forecasts of the transportation industry, and to explore regulatory changes. Further, Polenske advised a multiregional I-O approach to estimate the requirements of the transportation industry. Recently, a random-utility-based multiregional input-output (RUBMRIO) model has been introduced to explore the properties of solutions to many integrated land use-transportation models (Zhao and Kockelman, 2004).

In addition to the work of Plaut cited in the Introduction, some I-O studies of information and communications technology (ICT) are relevant. Uno (1989) found that information-based services became an important input for the service and manufacturing sectors, and that large amounts of industrial outputs are forwarded to service sectors. Finally, Saunders *et al*. (1994) pointed out that using input-output analysis to identify the relationship between telecommunications and economic activity might have potential problems: 1) lack of proper weighting by the proportions of total communications consumption by each industrial sector (for example, although the service and agriculture sectors consume 50% and 1% of all communications services, respectively, both sectors are treated as a single group without any weighting in the analysis) and 2) an inherent conceptual deficiency in the input-output approach (because the monetary value of transactions may not indicate the actual level of activities). We return to these limitations of I-O analysis later in this report (see Section 5.3).

### *2.3 Application of Input-Output Analysis to This Study*

This section briefly presents the application of input-output analysis to this study. The direct coefficient matrix discussed in the previous section is used to analyze the relationship between transportation and communications. The major application of input-output analysis to this study is a cross-sectional analysis for each time period, comparing results based on correlations between transportation and communications across multiple points in time.

Let $A_{Tjt}$ be the input coefficient (direct) 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). That is, for the direct table, $A_{Tjt}$ is the dollar value of transportation required to produce one dollar of output of industry j in year t. $\underline{A}_{T\bullet t}$ and $\underline{A}_{C\bullet t}$ are the vectors of coefficients across industries for a given year.

To analyze correlations between transportation and communications using the direct coefficient matrix, the input coefficients of transportation and communications in the input-output matrix are utilized.

As shown in Figure 2-1, the basic indicator of interest to this study is:

$$Corr_j(\underline{A}_{T\bullet t}, \underline{A}_{C\bullet t}), \quad (2.2)$$

where $\underline{A}_{T\bullet t}$ is the transportation input coefficient vector across industries for time period *t*, $\underline{A}_{C\bullet t}$ is the communications input coefficient vector across industries for time period *t*, and $Corr_j$ means correlation across industry *j*s. Thus, this analysis addresses the question: for a given year, what is the correlation across industries in the demand for transportation and communications? A positive correlation indicates complementarity (industries that require a lot of transportation also tend to require a lot of communications, and conversely); a negative correlation indicates substitution. We produce these cross-sectional correlations for each of the ten benchmark years between 1947 and 1997, and compare them across time. In Chapter 5 we present some examples illustrating potential relationships between transportation and communications for specific subcategories (utilities and manufacturing).

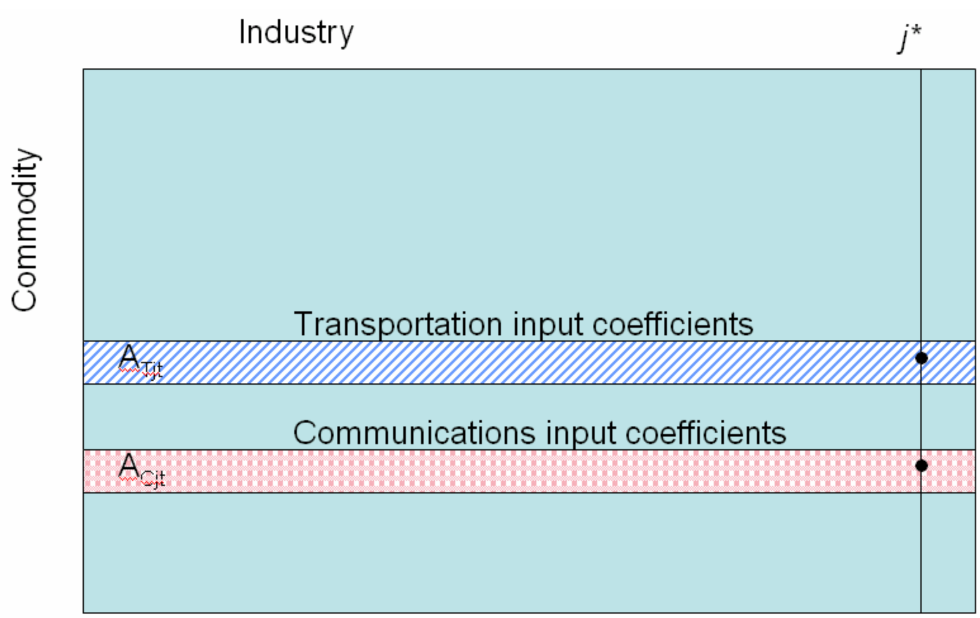



**Figure 2- 1. Schematic Showing the Cross-Sectional Correlation between Transportation and Communications across Industries**

# CHAPTER 3. DATA COLLECTION AND MANIPULATION

This chapter explains how the input-output data set was collected and manipulated for use in this study. Section 3.1 discusses the collection of data related to the benchmark input-output accounts. Section 3.2 explains several ways in which the data in each table were manipulated for the analyses of this study.

## *3.1 Data Collection*

Input-output matrices for the U.S. economy are available on the Internet (see www.bea.doc.gov/bea/dn2/home/i-o.htm) for the years 1982, 1987, 1992, 1996, 1997, 1998, and 1999. The I-O matrices fall into two different categories, benchmark and annual accounts. The benchmark I-O accounts are normally published every 5 years, whereas the annual accounts are extended and supplemented from the benchmark I-O accounts to fill in the remaining years (U.S. DOC, 1998). The website provides four benchmark I-O matrices as electronic files (spreadsheet or text types): 1982, 1987, 1992, and 1997. The annual I-O data sets from 1996 to 1999 are also available on the website. The older data are available only in paper-based versions published by the U.S. Department of Commerce.

A benchmark table is prepared using the most detailed data sources available, generally the economic censuses. Beginning in 1967, a benchmark I-O table has been prepared every 5 years to coincide with the quinquennial Economic Census. An annual table is an updated version of a previous benchmark table, using the current year data for output, and using the benchmark year interindustry relationships. For example, annual tables 1996-1999 are updated versions of the 1992 benchmark table, and the earlier 1961 table is also an updated version of the 1958 benchmark table. Furthermore, annual tables are published at a less detailed level, usually around 90 industries compared to the 400-500 industries in the benchmark tables. Due to these superior qualities of benchmark tables, and since an annual analysis is not necessary, we focused this study on the benchmark tables. We collected benchmark data that were published before 1982 from paper-based publications (*Survey of Current Business*, U.S. Department of Commerce). Altogether, benchmark tables have been published for the following years: 1947, 1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, and 1997. The latest benchmark table, for 1997, was published in December of 2002.

The paper-based benchmark I-O data sets (U.S. DOC, 1965, 1969, 1970, 1974, 1979, 1984) had to be converted into electronic files for the analysis. A detailed description of the conversion procedure is presented in Section 3.2.1 of this chapter. The tables are based on a 97-industry classification, except for 1997 which has a 134-industry classification. For some parts of the analysis, we aggregated industries into coarser industry groups based, for example, on Standard Industrial Classification (SIC) codes. Four scenarios regarding the aggregation of data are presented in Section 3.2.2.

Table 3-1 briefly summarizes the status of the benchmark I-O tables that were collected from the BEA website[3] and from the paper-based published versions. Moreover, the table also includes

[3] http://www.bea.doc.gov

the annual I-O accounts (1961, 1981, 1982, 1983, 1984, 1996, 1997, and 1998) that were collected.

The classification of industries is not the same across the years. So, it is important to document the variations in the classification of industries to confirm whether the data for each industry should be adjusted for the analyses or not. Table 3-2 explains the variations in classification of industries across the years. Some industry categories are consolidated, or divided over time. We take the classification of the year 1967 to compare the classification of industries for each year group. For convenience of explanation, the three year groups are named Year Group 1 (1947-1967), 2 (1972-1982), and 3 (1987-1992), respectively. Furthermore, the table contains three categories of changes: "Consolidation," "Division" and "Title changed". In the "Consolidation" category, industries are consolidated from two industries to one industry (e.g., Industries #5 and #6 are consolidated from 1987). In the "Division" category, single industries are divided into two to five industries (e.g., Industry #65 (Transportation Utilities) is divided into five detailed industry categories). The detailed description and comparison for classification of industries in 1997 is presented in Appendix A.

Furthermore, some titles of industries are changed with division, as noted in Year Group 3 (e.g., Industry #59: Motor vehicles and equipment is changed into #59A: Motor vehicles [passenger cars and trucks] and #59B: Truck and bus bodies, trailers, and motor vehicle parts). In the case of Industry #74 (Research and Development), it has data only for years 1947 and 1958, and no data for years 1963 and 1967, then it disappears from Year Group 2. But a new Industry #74 (Eating and drinking places) appears from year 1972. Also, Industries #81 (Business travel, entertainment and gifts) and #82 (Office supplies) disappear from Year Group 2. In the case of #85 from Year Group 2, a new title was created (Inventory valuation adjustment).

Although the classification of industries is a little inconsistent, all of the changes are relatively minor, occurring within the major category (one of the nine industry categories). Therefore, there is no big problem for comparing industry categories across years from 1947 to 1992. In the meantime, the classification of industries in 1997 has been changed into a new classification format which is based on the NAICS (North American Industry Classification System). So, the comparison of industry categories using NAICS and SIC (Standard Industrial Classification) for unclear categories is presented in Appendix B, not only to clarify whether industry categories of the two classification systems are comparable with each other or not, but also to determine how unclear industry categories based on NAICS can be changed to industry categories based on SIC if the specific category of NAICS is not apparently matched to one in the SIC system.

**Table 3- 1. Description of Input-Output Accounts Collection**

| Reference Year | Pub. Year, Mo. | Status | Tables | Note | Year of Classification system[3] |
|---|---|---|---|---|---|
| 1947 (B)[1] | 1970, Mar. | Hard Copy & Converted E-file | A. Interindustry Transactions<br>B. Direct Requirements Per Dollar of Gross Output<br>C. Total Requirements Per Dollar of Delivery to Final Demand | Got hard copy from Univ. of Illinois at Urbana Champaign | 1947 |
| 1958 (B) | 1965, Sep. | Hard Copy & Converted E-file | Same as above | | 1947 |
| 1961 (A)[2] *(1958 B)* | 1968, Jul. | Hard Copy | Same as above | Got hard copy from UC Berkeley | 1947 |
| 1963 (B) | 1969, Nov. | Hard Copy & Converted E-file | Same as above | | 1947 |
| 1967 (B) | 1974, Feb. | Hard Copy & Converted E-file | Same as above | | 1947 |
| 1972 (B) | 1979, Feb. | Hard Copy & Converted E-file | 1. The Make of Commodities by Industries<br>2. The Use of Industries by Commodities<br>3. Commodity-by-Industry Direct Requirements<br>4. Commodity-by-Commodity Total Requirements<br>5. Industry-by-Commodity Total Requirements | | 1972 |
| 1977 (B) | 1984, May | Hard Copy & Converted E-file | Same as year 1972 | | 1972 |

**Table 3- 1. — Continued.**

<table>
<tr><td colspan="2">1981 (A)<br>*(1977 B)*</td><td>1987, Jan.</td><td>Hard Copy</td><td>#1 and #2 (Make and Use Tables Only)</td><td></td><td>1972</td></tr>
<tr><td rowspan="2">1<br>9<br>8<br>2</td><td>*Hardcopy:*<br>1982 (A)<br>(1977 B)</td><td>1988, Apr. (hard copy)</td><td>Hard Copy</td><td>Hard Copy: #1 and #2</td><td></td><td>1972</td></tr>
<tr><td>*E-file:*<br>*1982 (B)*</td><td></td><td>Electronic File</td><td>E-file: #1 - #5 (text file)</td><td>E-file type: text file & spreadsheet file (transformed from text file using Matlab)</td><td>1972</td></tr>
<tr><td colspan="2">1983 (A)<br>*(1977 B)*</td><td>1989, Feb.</td><td>Hard Copy</td><td>#1 and #2</td><td></td><td>1972</td></tr>
<tr><td colspan="2">1984 (A)<br>*(1977 B)*</td><td>1989, Nov.</td><td>Hard Copy</td><td>#1 and #2</td><td></td><td>1972</td></tr>
<tr><td colspan="2">1987 (B)</td><td></td><td>Electronic File</td><td>Same as year 1972</td><td>E-file type: spreadsheet</td><td>1987</td></tr>
<tr><td colspan="2">1992 (B)</td><td></td><td>Electronic File</td><td>Same as year 1972</td><td>E-file type: spreadsheet</td><td>1987</td></tr>
<tr><td colspan="2">1996 (A)<br>*(1992 B)*</td><td></td><td>Electronic File</td><td>Same as year 1972</td><td>E-file type: spreadsheet</td><td>1987</td></tr>
<tr><td rowspan="2">1<br>9<br>9<br>7</td><td>1997 (A)<br>*(1992 B)*</td><td rowspan="2"></td><td rowspan="2">Electronic File</td><td rowspan="2">Same as year 1972</td><td>E-file type: spreadsheet</td><td>1987</td></tr>
<tr><td>1997 (B)</td><td>E-file type: text file & spreadsheet file (Redefinition)</td><td>1997</td></tr>
<tr><td colspan="2">1998 (A)<br>*(1992 B)*</td><td></td><td>Electronic File</td><td>Same as year 1972</td><td>E-file type: spreadsheet</td><td>1987</td></tr>
</table>

Notes:

[1] "(B)" in Reference Year means that the year has benchmark I-O tables.

[2] "(A)" in Reference Year means that the year has "Annual update" I-O tables. "*(1958 B)*" means that the annual data is updated from the 1958 benchmark.

[3] Year of Classification System refers to the last time the industry classification system was updated. For example, the 1967 accounts still used the classification system of 1947, whereas the 1972 accounts revised the industry categories.

**Table 3- 2. Variation of Classification of Industries [1]**

| | Year 1947 - 1967 (Group 1) | Year 1972 -1982 (Group 2) | Year 1987 - 1992 (Group 3) |
|---|---|---|---|
| Consolidation | [05, 06], [09, 10], [20, 21], [22, 23], [33, 34] and [44, 45]. | Same as 1947-1967 | Consolidated<br>[05+06], [09+10], [20+21], [22+23], [33+34] and [44+45]. |
| Division[2] | 26, 27, 29, 59, 65, 68, 69, 70, 71, 72, 73, 77 | Same as 1947-1967 | [26 → 26a, b], [27 → 27a, b],<br>[29 → 29a, b], [59 → 59a, b],<br>[65 → 65a, b, c, d, e], [68 → 68a, b, c],<br>[69 → 69a, b], [70 → 70a, b],<br>[71 → 71a, b], [72 → 72a, b],<br>[73 → 73a, b, c, d] and [77 → 77a, b] |
| Title changed[3] | 59: Motor vehicles and equipment<br>*59.01: Truck and bus bodies*<br>*59.02: Truck trailers*<br>*59.03: Motor vehicles and parts* | Same as 1947-1967 | 59a: Motor vehicles (passenger car and trucks) ("Motor vehicles" part of *59.03*)<br>59b: identical with sum of *59.01, 59.02* and *59.03* ("parts" part only) (1967) |
| | 73: Business services<br>*73.01: Miscellaneous business services*<br>*73.02: Advertising*<br>*73.03: Miscellaneous professional services* | 73: Business and professional services, except medical | 73a: Computer and data processing services, including own-account software (73.0104 of 1972)<br>73b: Legal, engineering, accounting, and related services (73.0301-73.0303 of 1972)<br>73c: identical with *73.01* plus *73.03* (1967)<br>73d: identical with *73.02* (1967) |
| | 74: Research and development<br>(No data for year 1963 and 1967) | 74: Eating and drinking places | 74: Eating and drinking places |
| | 80: Gross imports of goods and services | 80: Noncomparable imports | 80: Noncomparable imports |
| | 81: Business travel, entertainment and gifts<br>82: Office supplies | Disappeared | Disappeared |

[1] Based on the classification of year 1967.
[2] Refer to the tables of classification.
[3] Minor word changes were not considered.

**Table 3- 2. — Continued**

| | Year 1947 - 1967 (Group 1) | Year 1972 -1982 (Group 2) | Year 1987 - 1992 (Group 3) |
|---|---|---|---|
| Title changed | 83: Scrap and secondhand goods | Changed to 81 | Changed to 81 |
| | 84: Government industry | Changed to 82 | Changed to 82 |
| | 85: Rest of the world industry | Changed to 83 | Changed to 83 |
| | 86: Household industry | Changed to 84 | Changed to 84 |
| | None | 85 (new): Inventory valuation adjustment | 85 (new): Inventory valuation adjustment |

Note: 1) Data availability in years 1947 and 1958: from Industry #1 to Industry #82 are available for both direct and total requirements tables (i.e., none of the data for Industries # 83 to #86 are available in 1947 and 1958).
2) Data availability in years 1963 and 1967: except for Industry #74, direct coefficients are available for Industry #1 to Industry #83, and total coefficients are available for Industry #1 to Industry #82 (i.e., none of the data for Industry #74 and from Industries #84 to #86 are available in 1963; none of the data for Industry #74 and Industries #83 to #86 are available in 1967).

## *3.2 Data Manipulation*

For implementing our correlation analyses, the original tables needed to be manipulated. Three types of manipulation were conducted. Section 3.2.1 describes the conversion from paper to electronic. Section 3.2.2 discusses the classification of industries, focusing particularly on transportation and communications. Section 3.2.3 introduces four scenarios based on various levels of aggregation of industries that we analyzed throughout the study. In Section 3.2.4, the pairs of transportation and communications sub-industries selected for analysis are presented.

### 3.2.1 Conversion from Paper Tables to Electronic Files

Since the data sets that could only be collected in hard copy form (the six benchmark years from 1947 to 1977) had to be converted to electronic files, the following steps were implemented.

Step 1: Photocopy all the tables of direct and total input-output coefficients.
Step 2: Scan all the tables that were photocopied in Step 1, using Adobe Photoshop with the scanner.
Step 3: Save all the tables in "tif" format.
Step 4: Convert the scanned files into spreadsheet-type files using the OCR (Optical Character Recognition) software OmniPage Pro version 12.
Step 5: Confirm the data set and correct if necessary.

Table 3-3 shows the number of pages of hardcopy material that were converted into electronic files. The page numbers in the table are the original pages in the applicable *Survey of Current Business* published by the U.S. Department of Commerce.

**Table 3- 3. Number of Pages of Hardcopy Material to be Converted**

| Year | Direct Requirements Table | Total Requirements Table | Number of Pages |
|---|---|---|---|
| 1977 | pp. 63, 64, 65, 66, 67 | pp. 73, 74, 75, 76, 77 | 10 |
| 1972 | pp. 57, 58 ,59, 60, 61 | pp. 67, 68, 69, 70, 71 | 10 |
| 1967 | pp. 44, 45, 46, 47, 48, 49 | pp. 50, 51, 52, 53, 54, 55 | 12 |
| 1963 | pp. 36, 37, 38, 39, 40, 41 | pp. 42, 43, 44, 45, 46, 47 | 12 |
| 1958 | pp. 40, 41, 42, 43, 44 | pp. 45, 46, 47, 48, 49 | 10 |
| 1947 | pp. 21, 22, 23, 24, 25, 26, 27, 28, 29 | pp. 30, 31, 32, 33, 34, 35, 36, 37, 38 | 18 |
| | | | Total: 72 |

In the process of conversion (Step 4), since the accuracy of the OCR translation was not perfect, a confirmation process was needed for every I-O table. Several undergraduate students were hired to check the data set, after an interview and a test designed to assess their accuracy and attention to detail. The assistants initially worked by themselves, i.e., one assistant identified the cells with errors, and corrected the cells one by one on the spreadsheet. Then another assistant double-checked not only the corrected cells but the cells without errors. Thus, all errors on each page were corrected by one assistant, and checked by someone else. For the final confirmation, we randomly selected more than 30% of the cells, and confirmed their accuracy. Table 3-4 presents the distribution of error rates (percent of all cells on the page that had initial translation errors), with the estimated correction/checking time per page. In all, about 164 person-hours were required to complete the correction and checking process.

**Table 3- 4. Estimated Correction and Confirmation Time Calculated Using Error Rate Distribution**

| Proportion of Cells with Errors | # of Pages | Time per Page (min) | Estimated Time (min) |
|---|---|---|---|
| 0-5% | 10 | 100 | 1000 |
| 6-10% | 15 | 110 | 1650 |
| 11-20% | 20 | 130 | 2600 |
| 21-30% | 12 | 150 | 1800 |
| 31-40% | 5 | 165 | 825 |
| 41-50% | 5 | 185 | 925 |
| More than 50% | 5 | 200 | 1000 |
| Total | 72 | | 9800 |

### 3.2.2 Industry Classification

There are nine aggregate industry categories in the input-output accounts. Among those categories, the manufacturing sector (#4) and the transportation, communications, and utilities sector (#5) have transportation and communications components. This study focuses on these sectors (#4 and #5), and more finely classifies the industries corresponding to both transportation and communications. Table 3-5 presents the original 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). We refer to the transportation and communications manufacturing and utilities industries (i.e. #10, #11, #13, and #14) as "selected categories."

The lower portion of the table lists the exact groups comprising each of the selected categories, for three different time periods: (1) 1987 and 1992 benchmark, (2) 1997 benchmark, and (3) 1947 through 1982 benchmark. For example, category #10, Transportation Manufacturing, is composed of five industry groups: #16 (Motor vehicles: passenger cars and trucks), #17 (Truck and bus bodies, trailers, and motor vehicles parts), #18 (Aircraft and parts), #19 (Other transportation equipment), and #20 (Petroleum refining and related products).

Finally, categories #30 and #31 constitute the aggregate (manufacturing plus utilities) categories for transportation and communications, respectively: #30 (All Transportation Manufacturing and Utilities, #10 + #13), and #31 (All Communications Manufacturing and Utilities, #11 + #14).

## Table 3- 5. Classification of Industries in the Input-Output Accounts

| No. | Classification | 23 → 13 categories (1987 and 1992) [1)] | 29 → 13 categories (1997) [2)] | 18 → 13 categories (1947–1982) [3)] |
|---|---|---|---|---|
| 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 | 23A+23B+24A+24B+25+26+27A+27B+27C+27D | (23–27) |
| 14 | All Communications Utilities | 28+29 | 28+29A+29B | 28+29 |
| 15 | Utilities except Transportation & Communications Utilities | | | |

| No. | Code | (1) 1987 and 1992 Benchmark | No. | Code | (2) 1997 Benchmark (Redefined by using NAICS) |
|---|---|---|---|---|---|
| 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 |

Notes: 1) In 1987 and 1992, Scenario 2 used the 23 categories 1-3, 6-9, 12, 15, and 16-29. Scenario 3 used the 13 categories 1-3 and 6-15.

2) In 1997, Scenario 2 used the 29 categories 1-3, 6-9, 12, 15, and 16-29B. Scenario 3 used the 13 categories 1-3 and 6-15.

3) In 1947 through 1982, Scenario 2 used the 18 categories 1-3, 6-9, 12, 15, and (16+17)-29. Scenario 3 used the 13 categories 1-3 and 6-15.

**Table 3- 5. — Continued**

| (1) 1987 and 1992 Benchmark | | | (2) 1997 Benchmark (Redefined by using NAICS) | | | |
|---|---|---|---|---|---|---|
| 23 | 65A | Railroads and related services; passenger ground transportation | 23A | 4820 | Rail transportation | |
| | | | 23B | 4850 | Transit and ground passenger transportation | |
| 24 | B | Motor freight transportation and warehousing | 24A | 4840 | Trucking transportation | |
| | | | 24B | 4930 | Warehousing and storage | |
| 25 | C | Water transportation | 25 | 4830 | Water transportation | |
| 26 | D | Air transportation | 26 | 4810 | Air transportation | |
| 27 | E | 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 Transportation Manufacturing and Utilities | 10+13 | 30 | All Transportation Manufacturing and Utilities | | 10+13 |
| 31 | All Communications Manufacturing and Utilities | 11+14 | 31 | All Communications Manufacturing and Utilities | | 11+14 |

| (3) 1947 through 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 |

For more than sixty years, the Standard Industrial Classification (SIC) system constituted the basic typology of industries in the U.S. economy, so that the classification of industries in I-O accounts was also based on the SIC system. However, as mentioned in the previous section, the classification of industries in the I-O accounts of 1997 (and onward, when they become available) is based on the North American Industry Classification System (NAICS). Lawson *et al*. (2002, pp. 19-20) note the major changes in the 1997 benchmark I-O accounts. Specifically, the NAICS "provides the accounts with a more relevant system for classifying industries, especially for services, than its predecessor Standard Industrial Classification (SIC) system, which originated in the 1930s. As a result, the 1997 benchmark accounts provide greater detail on service industries–including those in the new sector 'information,' which accounted for 4.4 percent of total value added."

### 3.2.3 Four Scenarios Based on the Aggregation Level

An important decision in the analysis is the level of aggregation over which to take the correlation – i.e. the number of industries J, or the number of elements in the row vectors of Figure 2-1. The more disaggregate the industry classification (i.e. the larger J), the more that random variation at the "micro" level may obscure general tendencies; on the other hand, a very aggregate classification (small J) may combine so many industries, and result in such a small number of cases, that it is also difficult to detect underlying relationships.

This analysis will experiment with different levels of aggregation to identify what influence that has on the results. At one extreme, we retain the industries in their (nearly) most disaggregate form, ranging from 79 to 131 depending on year. At the other extreme, we analyze just the nine top-level industry categories. In between, we analyze two scenarios distinguished by how finely the transportation and communications industries are disaggregated, keeping the remaining industries in their most aggregate form. Thus, we have:

- Scenario 1: The most disaggregated data set is used (79-131 categories).
- Scenario 2: 18 aggregated industries are used from 1947 to 1982, 23 aggregated industries are used from 1987 to 1997.
- Scenario 3: 13 aggregated industries are used.
- Scenario 4: The most aggregated 9 industries are used.

Table 3-6 summarizes the data available for the ten benchmark years for four analysis scenarios. The number in each cell is the number of industry categories used for that scenario. Appendix C shows the schematic diagram for spreadsheets in MS Excel using sample year 1992, which explains how selected industry categories were calculated by using direct input-output coefficients from Scenario 1 to Scenario 4.

**Table 3- 6. Number of Industry Categories in Each Scenario, for the Ten Benchmark Years**

| Scenario | | 1947 | 1958 | 1963 | 1967 | 1972 | 1977 | 1982 | 1987 | 1992 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario 1 | Direct | 82 by 82 | 82 by 82 | 83 by 83 | 83 by 83 | 81 by 79 | 81 by 79 | 81 by 79 | 97 by 94 | 97 by 94 | 134 by 131 |
| | Total | 82 by 82 | 82 by 82 | 82 by 82 | 82 by 82 | 79 by 79 | 79 by 79 | 79 by 79 | 94 by 97 | 94 by 97 | 131 by 134 |
| Scenario 2 | | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 23 | 23 | 29 |
| Scenario 3 | | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| Scenario 4 | | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |

Note 1) The numbers in each cell are the number of industry categories used for that scenario.
2) Years 1947 and 1958: Do not include Industry #83 (Scrap, Used & Secondhand Goods).
3) Years 1963 and 1967: There is no Industry #74 (Research and Development) in both direct and total table, and there is no Industry #83 in the total table.
4) For years 1987 and 1992, the last four rows (Industries #82, #83, #84, and #85) and the last three columns (Industries #82, #84, and #85) are entirely zero, and included in the direct table. Three columns (Industries #80, #81, and #83; entirely zero) are included in the total table.

The category numbers below correspond to those in Table 3-5.

Scenario 1: All industries (the most disaggregate case)
Scenario 2: 18 industries: 1 2 3 16+17 18 19 20 21 22 12 23+24+25+26+27 28 29 15 6 7 8 9
23 industries: 1 2 3 16 17 18 19 20 21 22 12 23 24 25 26 27 28 29 15 6 7 8 9
Scenario 3: 13 industries: 1 2 3 10 11 12 13 14 15 6 7 8 9
Scenario 4: 9 industries: 1 2 3 4 5 6 7 8 9

### 3.2.4 Selected Industry Categories for Analyses

The direct I-O accounts are manipulated to obtain the correlation coefficients among five pairs of the following six selected categories:

- 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)
- Selected Category #14: All Communications Utilities (28+29)
- Selected Category #30: All Transportation Manufacturing and Utilities (10+13)
- Selected Category #31: All Communications Manufacturing and Utilities (11+14)

Specifically, as shown in Figure 3-1, we analyze the pairwise correlations of each transportation sub-category with each communications sub-category, and the two overall categories, namely Corr (#10, #11), Corr (#10, #14), Corr (#11, #13), Corr (#13, #14), and Corr (#30, #31). Plaut (1999), by contrast, only analyzed Corr (#13, #14) for one year.

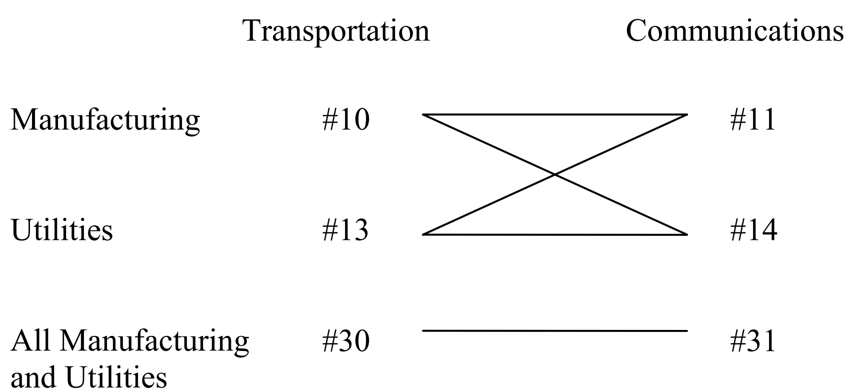



**Figure 3- 1. Selected Pairwise Correlations of Industry Categories of Transportation and Communications**

# CHAPTER 4. METHODOLOGICAL APPROACH

This chapter describes several key aspects of the analysis methodology. Section 4.1 explains the column normalization of the I-O accounts, which is needed for creating the aggregated Scenarios 2, 3, and 4. Section 4.2 introduces the weighting factors named ECBWs (Economic Contribution-Based Weights), which are applied to every I-O account to weight each industry according to its economic contribution. Section 4.3 discusses the Spearman correlation coefficient, and how it is interpreted.

## *4.1 Column Normalization of the I-O Accounts*

As discussed in Section 3.2.3, the aggregated Scenarios 2, 3, and 4 are created to consolidate the industries other than transportation and communications, while examining both finer and coarser levels of the industries corresponding to transportation and communications. As presented in Table 3-5, there are nine top-level industries, which are numbered from 1 to 9 in the table. So, Scenario 4 is the most aggregate among the four scenarios, consisting of just the nine main industries. Scenarios 2 and 3 are created to see the difference between finer and coarser aggregation of the transportation and communications sub-industries of Industries #4 and #5 in the table, holding the other industries at the top-most level of aggregation. These particular scenarios are created and analyzed to investigate whether changing the level of aggregation produces different patterns of relationship between transportation and communications.

As shown in Figure 4-1, suppose that in Scenario 1, J=94 and j = 1, 2, 3, 4 indexes the sub-industries of main industry 1 (Agriculture, Forestry, and Fisheries). Then, since $a_{Tj}$ = $ value of T needed to produce $1 of output in sub-industry j, $\sum_{j=1}^{4} a_{Tj}$ = $ value of T needed to produce $4 of output in the Agriculture, Forestry, and Fisheries industry. It can easily be seen that the aggregation process will distort the "unit" interpretation of the input coefficients (especially since each main industry comprises a different number of sub-industries), unless it is corrected.

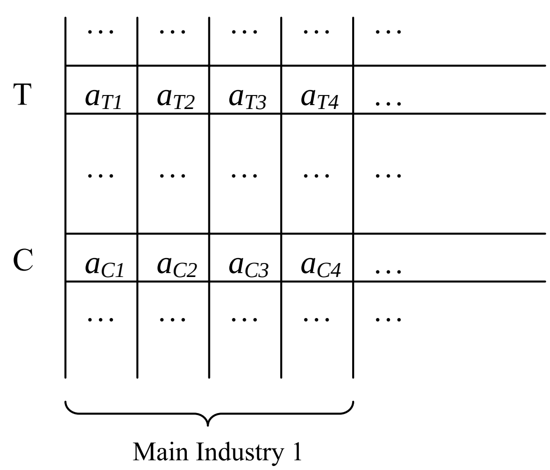



**Figure 4- 1. Schematic of Sub-industries Comprising a Main Industry**

Thus, the aggregate coefficients are normalized by dividing them by the number of sub-industries being aggregated, so that each normalized coefficient $a_{ij'}$ still represents the $ value of industry *i* needed to produce $1 of output from (aggregated) industry *j'*.

### *4.2 Economic Contribution-Based Weight (ECBW)*

Although the unit interpretation of the input coefficient is important in many conventional applications of I-O analysis, it is problematic in our context of investigating the relationship between transportation and communications across industries. The reason is that we would like for the resulting correlation to give us an economy-wide picture of the general relationship between transportation and communications. But the unit interpretation of the individual $a_{ij}$s distorts that picture by giving each industry *j* equal weight in the correlation (i.e., by being tied to $1 of output in industry j), regardless of whether j constitutes an enormous portion of the overall economy, or a tiny one. To correct this, we need to weight each input coefficient by the dollar value of the contribution of the "receiving" industry (*j*) to the overall economy.

Thus, this study introduces the economic contribution-based weight (ECBW) that is applied to each I-O coefficient of the corresponding industry. The ECBW is created by using the total value of production of each industry. Since the Make table of the I-O accounts provides the monetary value (in millions of dollars at producers' prices) of production of each commodity (column) by each industry (row), the row-sum is the total value of production (across all commodities) of each industry. Thus, the proportion of total economic production attributable to industry j is $\frac{X_j}{\sum_{j'=1}^{N} X_{j'}}$,

where *j*: Industry index

$X_j$: Total value of production of industry *j* (*j*th row-sum of the Make table)

*N*: Number of industries contributing non-zero production to the economy.

Since the standard error of the test statistic decreases with increasing sample size, artificially inflating the sample size would artificially improve the precision of the estimated correlations, making it easier to find statistical signficance when in fact there was none. Thus, to preserve the validity of the statistical tests, applying the weights should ideally leave the overall sample size unchanged. That is, the sum of the ECBWs should be equal to N, the number of industries contributing non-zero weight. Accordingly, we initially weighted each output industry *j* by

$$ECBW_j = \frac{X_j}{\sum_{j'=1}^{N} X_{j'}} \times N \;, \qquad (4.1)$$

so that $\sum_{j=1}^{N} ECBW_j = N$. For example, in Scenario 1, the sum of the ECBWs was equal to 93 (=*N*) in 1992. For Scenarios 2, 3, and 4 the sums of the ECBWs were 23 (for 1987 through 1997; see Table 3-6 for other years), 13, and 9, respectively. Using the "Weight Cases" option in SPSS, the *j*th economic contribution-based weight is applied to the *j*th element of the T and C I-

O coefficient vectors. The ECBWs obtained in this way, of Scenarios 2 through 4 for the ten benchmark years (1947-1997), are shown in Appendix D.

This approach proved to pose a problem, however. The weights need to be integer-valued, so SPSS rounds them up or down to the nearest integer before applying them (and then simply replicates the observation that integer number of times in the calculation). This reduced the precision of the weights considerably, and in particular, weights less than 0.5 were rounded down to zero, removing those industries from the calculation entirely. Multiplying the ECBWs by a large constant, e.g. 100, would eliminate that problem, but would render the statistical tests of significance of the correlations invalid, as mentioned above. Arguably, the original approach is a reasonable first-order approximation to computing the correlation, since industries with relatively small contributions to the economy would in any case contribute little to the calculation. In fact, comparisons of the values of the correlations computed both ways (with weights calculated from equation (4.1) and with weights 100 times those) found no differences in sign for statistically significant correlations. Thus, we believe that the more reliable hypothesis-testing properties of the original approach makes it preferable, and those are the results presented in Section 5.2.

### *4.3 Interpretation of Correlation Coefficients*

The "Spearman correlation analysis" module of the statistical analysis software package SPSS (Version 11.0) produces the correlation coefficients, with p-values, for the five combinations described in Section 3.2.4, across the ten benchmark years and four scenarios that are based on the aggregation levels mentioned in Section 3.2.3. Therefore, the statistically significant correlation coefficients of each combination, which can be positive or negative, can be used for examining the relationships between transportation and communications. In view of the relatively small number of cases over which the correlation is taken here (9 for Scenario 4; 13, 18-29, and 81-131 for Scenarios 3, 2, and 1, respectively), 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.,* 1986), which roughly corresponds to a p-value of 0.3. 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.

Following Plaut (1997), we use the Spearman correlation rather than the Pearson correlation in this analysis. The Spearman correlation is a nonparametric correlation measure. Since the input-output coefficients are not normally distributed, the Pearson correlation coefficient is not strictly appropriate. In our context, the equation of the Spearman rank correlation is

$$r_s = \frac{\sum (R_{jC} - \overline{R}_C)(R_{jT} - \overline{R}_T)}{\sqrt{\sum (R_{jC} - \overline{R}_C)^2 \sum (R_{jT} - \overline{R}_T)^2}}, \quad (5.2)$$

where $R_{jC}$ is the rank of the $j$th element of the vector $\underline{A}_{C\bullet t}$, $R_{jT}$ is the rank of the $j$th element of the vector $\underline{A}_{T\bullet t}$ ($R_{jC}$, $R_{jT} \in \{1, 2, \ldots, J\}$), $\overline{R}_C$ 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 $R_{jT}$. Here, the smallest value in the vector gets rank #1, and the largest value in the vector gets rank #J.

An above-average rank $R_{jC}$ means that industry j requires a relatively large communications input, compared to the average industry. Thus, 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.

In this study, a Spearman correlation coefficient can indicate two different relationships, complementarity and substitution. If the correlation coefficient is positive, it implies that the relationship between the two categories is complementarity because the two inputs tend to be used together. For example, the more (or the less) industries require transportation utilities, the more (or the less) industries require communications utilities. 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.

# CHAPTER 5. HYPOTHESES AND RESULTS

We have referred throughout this report to the possible relationships between transportation and communications, particularly substitution and complementarity. Before turning to the results of this study, it is useful to bring some concreteness to those potential relationships, by suggesting specific ways in which substitution and complementarity might occur for the industrial inputs of transportation and communications. Thus, in Section 5.1 of this chapter, we provide prospective examples of each type of relationship. In Section 5.2 we present the results of the cross-sectional analysis using the direct coefficients matrix. Section 5.3 briefly describes the limitations of this analysis.

## *5.1 Hypotheses*

As indicated earlier, in this study we analyze transportation and communications manufacturing inputs as well as utilities inputs. Each transportation category could be related to each communications category, for four possible relationships. Since each relationship could be either substitution or complementarity (if there is a significant relationship at all), there are eight types of relationships that might underlie the empirical results. Tables 5-1 and 5-2 provide examples of relationships, to illustrate the mechanisms that might be at work within industries (see, e.g., Niles, 1994). All of these relationships are plausible, and so it is reasonable to hypothesize that either substitution or complementarity might be the outcome in any given case. We might also see shifts over time, as one or another of the particular mechanisms becomes stronger.

Since the data analyzed in this study span a 50-year time period (from 1947 to 1997), to put the examples of Tables 5-1 and 5-2 in context it is useful to review some key milestones in the development of telecommunications technologies:[4]

- Electrical telegraph: A system that uses electric signals to transmit written messages without the physical transport of letters. The British "needle" telegraph was in use by 1830, but the first practical electrical telegraph system (including the "Morse Code" for transmission) was developed in 1844 by Samuel Morse and Alfred Vail.
- Telephone: Although Alexander Graham Bell is widely associated with the origin of the telephone in 1876, the Italian inventor Antonio Meucci is officially credited with its invention in 1849. Telephone is still the most popular and widely used communications technology, which transmits speech as well as data by means of electric signals.
- Fax: Referring to a means of transferring photocopies (or "facsimiles") of documents over the telephone network, the original technology was invented in 1929 by Rudolf Hell, although it did not become popular until the 1980s.
- Email: Electronic mail started in 1965, which actually predates the Internet. Email was an essential tool in building the Internet. It has become increasingly popular from the late 1980s onward, and is used for routine communications by many if not most American adults today.

[4] www.encyclopedia.thefreedictionary.com and www.blinkenlights.com, accessed May 19, 2004.

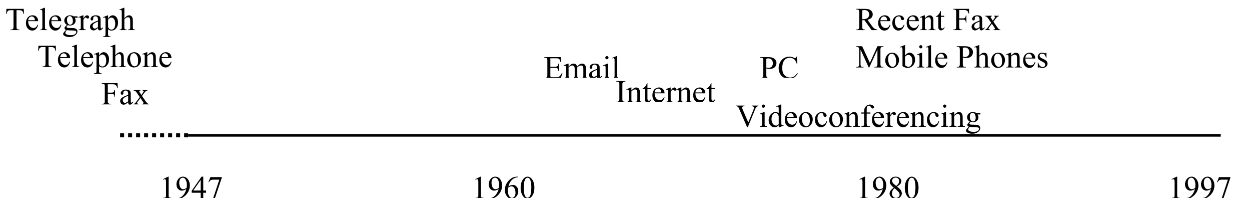
**Table 5- 1. Examples of Potential Relationships between Transportation and Communications (Substitution)**

| Examples \ Impacts on | Transportation | | Communications | |
|---|---|---|---|---|
| | Manufacturing | Utilities | Manufacturing | Utilities |
| **Substitution** | | | | |
| Fax, email replacing physical delivery of documents | Less gasoline | Less use of delivery services | More fax equipment and computers | More use of phone service |
| Telephone, videoconferencing replacing physical passenger travel | Less gasoline, fewer company cars | Less air travel | More videoconferencing and network equipment | More use of phone service |
| 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 |

- PC: The first personal computer was the "Apple I", introduced in 1976. In 2001, about 56.5 percent of the U.S. households had personal computers (U.S. DOC, 2002).
- Internet: The core network technology was built in 1969 as the ARPANET (Advanced Research Projects Agency Network) of the U.S. Department of Defense. On January 1, 1983, the ARPANET changed its core networking protocols from NCP (Network Control Program) to TCP/IP (Transmission Control Protocol), launching today's Internet. The worldwide web (WWW), which is the hypertext system that operates over the Internet, was released in 1991. About 50.5 percent of the U.S. households in 2001 had Internet connections (U.S. DOC, 2002).
- Mobile phone: The technology for wireless voice communications beyond the short-range has existed since the 1950s. However, mobile phones started becoming popular in the 1980s with the introduction of "cellular phones".
- Videoconferencing: Videoconferencing uses the public telephone network, a dedicated private telecommunications network, or, most recently, the Internet to transmit visual images (up to full motion real-time video) among meeting participants in different physical locations. Videoconferencing technology has been commercially available since about the late 1970s (U.S. DOC, 1977). It has undergone considerable improvement since the 1980s, but its adoption and use remain somewhat limited even today.

**Table 5- 2. Examples of Potential Relationships between Transportation and Communications (Complementarity)**

| Impacts on / Examples | Transportation | | Communications | |
|---|---|---|---|---|
| | Manufacturing | Utilities | Manufacturing | Utilities |
| **Complementarity** | | | | |
| ICT permits decentralization of organizations (e.g. detachment of back office functions), increasing travel between 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 transport (ground, air, and marine) services | 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 *less* efficient deliveries and less full loads | 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, more 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 and therefore increasing its demand | More gasoline, transportation vehicles | More use of transport services | More ICT equipment | More use of ICT services |




### *5.2 Results*

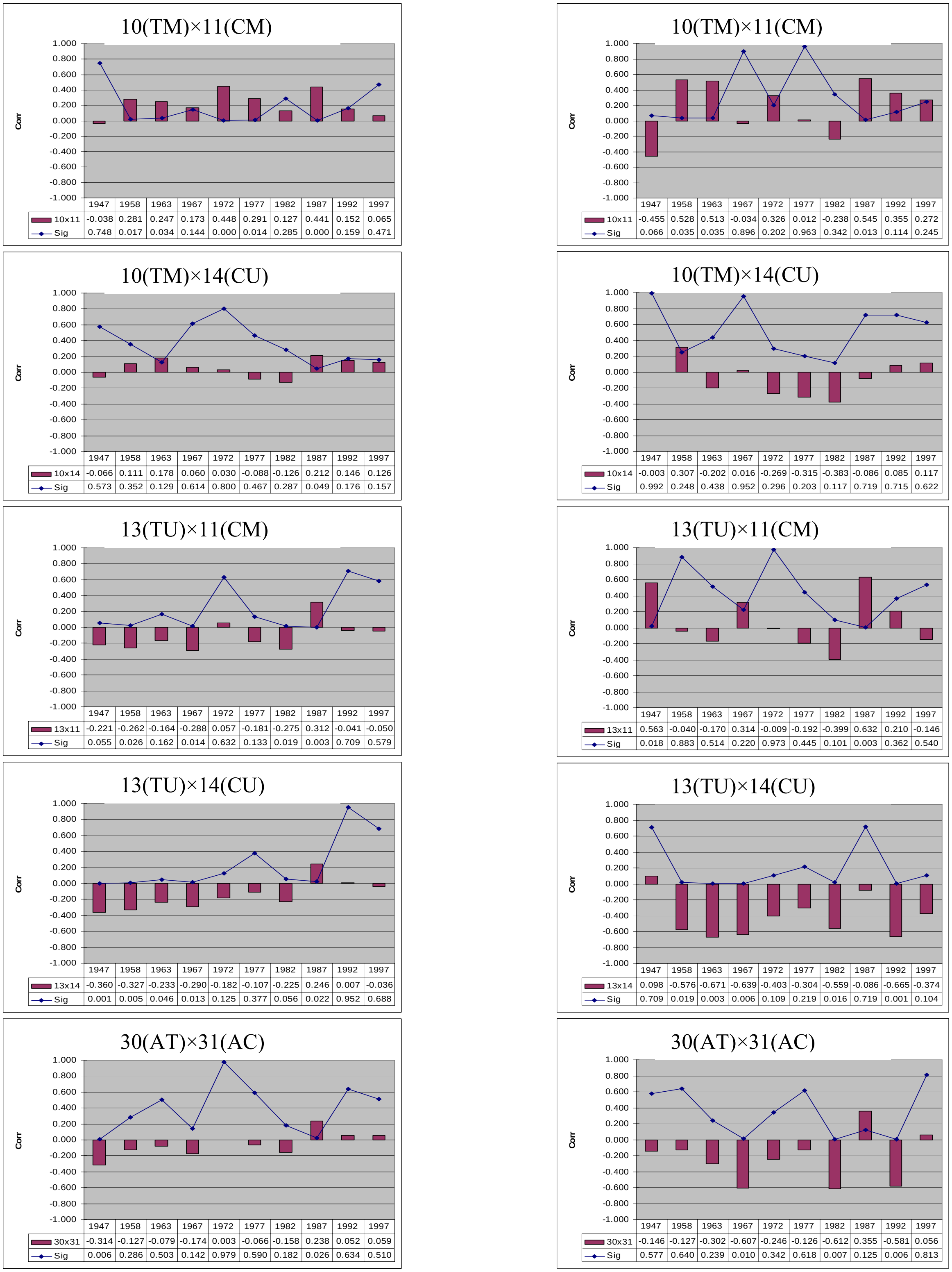
This section describes the results of the cross-sectional analysis of the direct tables. Recall that the direct input coefficient represents the dollar amount of commodity i directly required by industry j to produce a dollar of its output. This coefficient can be taken from the "commodity-by-industry direct coefficient matrix" table of the input-output accounts (industries and commodities constitute essentially the same categories; the term used depends on the particular emphasis of the context). We compute the Spearman (non-distributional) correlations between direct coefficients, $A_{Tjt}$ and $A_{Cjt}$, over $j$, to conduct a cross-sectional analysis for each time period t. Furthermore, we compare results across time based on the five sets of correlations described in Section 3.2.4, for Scenarios 1-4. Consequently, 200 correlation coefficients in all are computed in this study (5 correlations / year × 10 years × 4 scenarios).

Figures 5-1a through d graphically show the Spearman correlation coefficients, together with their significance levels (p-values), for the four scenarios representing different levels of industry aggregation. Each figure contains five comparison graphs along the ten benchmark years[5]. The correlation coefficients fall between -1 and 1. As explained in previous chapters, if the value is negative, the relationship between transportation and communications constitutes substitution. If the value is positive, the relationship represents complementarity. P-values fall between 0 and 1; if the p-value is close to zero, the coefficient is statistically significant, meaning statistically different from zero. For example, if the p-value is 0.098, we are 90.2% sure of being right if we reject the null hypothesis of no correlation.

Table 5-4 summarizes the numbers of significant positive and negative Spearman correlations for each of the five sets of correlations (i.e. 10x11, 10x14, 13x11, 13x14, and 30x31; refer to Table 5-3) and each of the four scenarios (ranging from the most disaggregate to the most aggregate groupings of industries). Of course, the number of significant coefficients varies according to the significance level chosen. Here, because of our small sample size and the exploratory nature of our study, we use the relatively generous 80% confidence level (corresponding to $p = 0.2$) as our threshold for significance.

[5] These figures show all ten benchmark years on one graph, one graph for each comparison pair, grouped by scenario. To facilitate other analyses, Figures 1-10 of Appendix E present one graph for each comparison pair, with all four scenarios on one graph, grouped by year; and Figures 11-15 present one graph for each year, with all four scenarios on one graph, grouped by comparison pair.

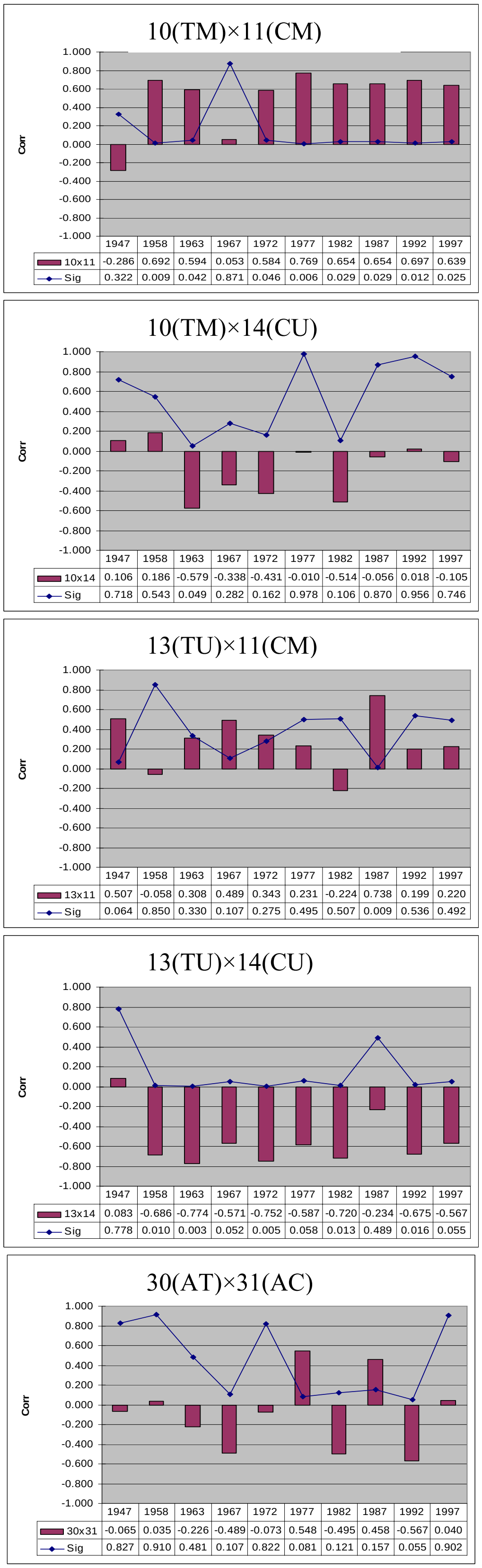
**Figure 5- 1. Spearman Correlations from Direct Coefficients Matrix, 1947-1997 Benchmark Years**



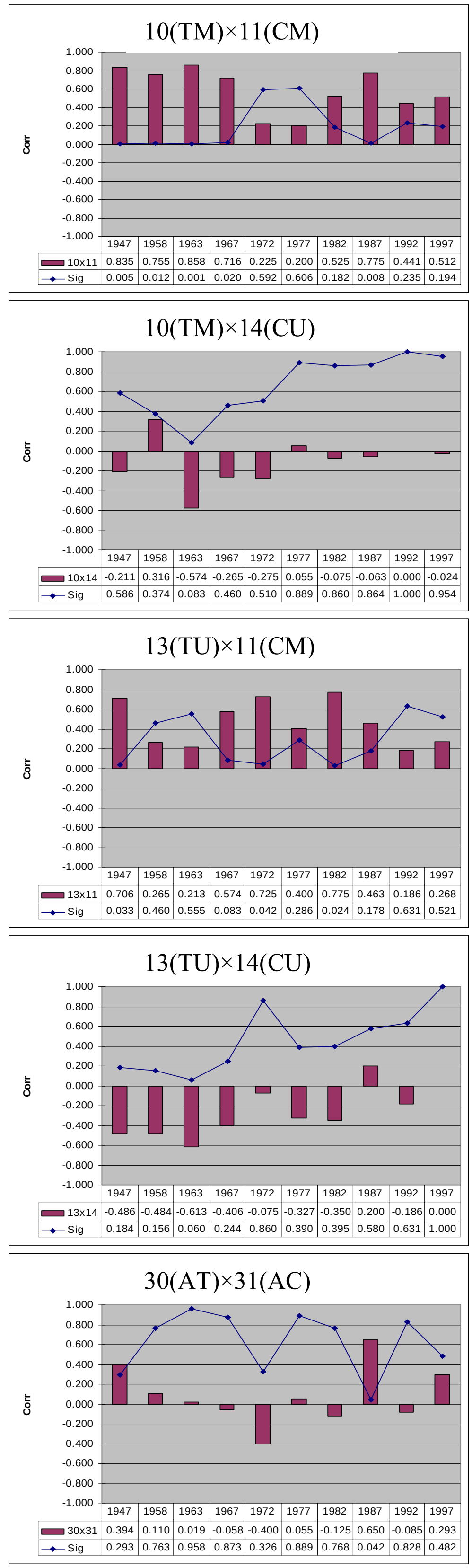

**a. Scenario 1: The Most Disaggregate Scenario (79-131 categories)**

**b. Scenario 2: More Aggregate Scenario (18-29 categories)**

Note: TM(10): Transportation Manufacturing; CM(11): Communications Manufacturing; TU(13): Transportation Utilities CU(14): Communications Utilities; AT(30): All Transportation; CT(31): All Communications




**c. Scenario 3: Next Most Aggregate Scenario (13 categories)**




**d. Scenario 4: The Most Aggregate Scenario (9 categories)**

Note: TM(10): Transportation Manufacturing; CM(11): Communications Manufacturing; TU(13): Transportation Utilities CU(14): Communications Utilities; AT(30): All Transportation; CT(31): All Communications

The transportation manufacturing and communications utility pair (10×14) and transportation utility and communications manufacturing pair (13×11) present mixed patterns (as can also be seen in Figure 5-1), with relatively fewer significant correlations overall, and a closer balance between positive and negative correlations for those that *are* significant. This result might be expected since the potential relationships in Section 5.1 include both substitution and complementarity. In other words, since either sign is plausible, it is not surprising that effects in each direction could frequently cancel and that significance in both directions can be found. Thus, our assessment of this result would be "mixed effects" rather than "no effects".

**Table 5- 3. Definition of Each Category**

| No. | Definition |
|---|---|
| **10** | Transportation Manufacturing |
| **11** | Communications Manufacturing |
| **13** | Transportation Utilities |
| **14** | Communications Utilities |
| **30** | All Transportation Manufacturing and Utilities (10+13) |
| **31** | All Communications Manufacturing and Utilities (11+14) |

**Table 5- 4. Numbers of Significant (p=0.2) Positive and Negative Spearman Correlations**

| Category Pairs | | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Total |
|---|---|---|---|---|---|---|
| **10×11** | + | 7 | 5 | 8 | 7 | 27 |
| | – | 0 | 1 | 0 | 0 | 1 |
| **10×14** | + | 4 | 0 | 0 | 0 | 4 |
| | – | 0 | 2 | 3 | 1 | 6 |
| **13×11** | + | 1 | 3 | 3 | 5 | 12 |
| | – | 6 | 1 | 0 | 0 | 7 |
| **13×14** | + | 1 | 0 | 0 | 0 | 1 |
| | – | 6 | 7 | 8 | 3 | 24 |
| **30×31** | + | 1 | 1 | 2 | 1 | 5 |
| | – | 3 | 3 | 3 | 0 | 9 |

Notes: Scenario 1: The most disaggregate level (79-131 categories); Scenario 2: More aggregate level (18-29 categories); Scenario 3: Next most aggregate level (13 categories); Scenario 4: The most aggregate level (9 top-level categories). Each scenario-category pair combination has ten correlations, one for each benchmark year, for a total of 40 correlations per category pair. Thus, the number of insignificant correlations can be deduced by subtraction in each case (e.g., 12 for the 10×11 pair, 30 for 10×14, and so on).

Furthermore, the relationship (30×31) between all transportation manufacturing and utilities (30) and all communications manufacturing and utilities (31) presents a similarly indistinct pattern, with many insignificant correlations and mixed signs for those that are significant. Given the results for the constituent industries described above, this is not surprising. Although the pattern is not strong due to the large number (65%) of insignificant results, the number of negative values (9) does outweigh the number of positive values (5), which could be interpreted to mean that the overall relationship between transportation and communications might be closer to substitution — at least from 1947 to 1997.

Finally, it is important to compare the aggregate and disaggregate results to see whether there is coherence across the four scenarios. As shown in the four figures and in Table 5-4, the manufacturing pair (10×11) and utility pair (13×14) seem to have consistent patterns except for two significant values that have signs opposite to the rest: the significant negative correlation in 1947 on Scenario 2 of 10×11 (Figure 5-1b) and the significant positive correlation in 1987 on Scenario 1 of 13×14 (Figure 5-1a).

However, the mixed pairs, 10×14 and 13×11, demonstrate different kinds of patterns compared with the manufacturing pair (10×11) or the utility pair (13×14). As shown in the graphs and the table, the dominant sign of the correlations reverses when moving from Scenario 1 to Scenario 4. In the 10×14 pair, the significant values are positive in Scenario 1 while there are only negative significant values in Scenarios 2, 3, and 4. The coefficients for the most disaggregate level (Scenario 1) are also smaller than those for the more aggregate levels (Scenarios 2, 3, and 4). For the 13×11 pair, on the contrary, all but one of the significant correlations are negative in Scenario 1 while all but one are positive in Scenarios 2, 3, and 4. Similar to 10×14, however, the coefficients for the most disaggregate level (Scenario 1) are smaller than those of the aggregate levels (Scenarios 2, 3, and 4).

These results suggest that an ecological fallacy is at work since there is an observable difference (sign and coefficient) between the disaggregate and aggregate scenarios. It is preferable to focus on Scenario 1 since, as the most disaggregate, it is the scenario closest to the level of the individual actors (single companies). With that in mind, revisiting Table 5-4 and concentrating on Scenario 1 reinforces the findings of predominant complementarity for the manufacturing pair (10×11) and substitution for the utilities pair (13×14). We also see clearer pictures of complementarity between transportation manufacturing and communications utilities (10×14), and substitution between transportation utilities and communications manufacturing (13×11) as well as transportation and communications overall (30×31) (although the first and last of those results are somewhat weakly based on only four significant correlations out of 10).

Closer scrutiny of Scenario 1 in Figure 5-1a reveals another striking pattern. For all five comparison pairs, the 1987 benchmark year marks a break of some kind with the preceding benchmark year. For the manufacturing pair (10×11), the 1987 correlation is substantially higher than those of the adjacent benchmark years, and appears to mimic the peak-and-decline cycle observed to start 15 years earlier in 1972. For the utilities pair (13×14), transportation utilities – communications manufacturing pair (13×11), and "all" pair (30×31), 1987 marks the first positive (and strongly significant) correlation in the entire series (following seven that are either significantly negative or essentially zero), with the remaining two correlations essentially zero. The picture for the transportation manufacturing – 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 ones.

Whether the positive spikes at 1987 represent a long-term structural shift from substitution to complementarity or an anomalous year in a pattern that is returning to negative (or zero) is difficult to tell from the limited information in the following years. Certainly, it will be critical to examine the results for the 2002 benchmark year once they become available. For now, it must simply be stated that the dominant findings of substitution for the latter three of the five category pairs for Scenario 1 may be a historical artifact that is changing, since the single significant positive correlation in each of those three cases is the most recent year (1987) for which a coefficient in the series is significant. This observation also makes our findings for the utilities pair (13×14) somewhat more compatible with Plaut's finding of complementarity, although we do see a significant negative correlation for the preceding benchmark year – 1982, the closest year to Plaut's analysis of European data (1980) finding the opposite. Plaut (1997) found complementarity between transportation utilities and communications utilities which was quite significant (at the 1% level), for almost all countries within the EC.

### *5.3 Limitations of This Study*

In Chapter 2, we cited Saunders *et al.* (1994) as saying that there are two potential problems when we use input-output analysis to examine the relationship between telecommunications and economic activity. The first potential problem is the lack of proper weighting for each industrial sector, and the second one is the inherent conceptual deficiency in the input-output approach. In Section 4.2 we introduced the Economic Contribution-Based Weight (ECBW) to properly weight each industrial sector. That is, we weight each input coefficient by the dollar value of the contribution of the "receiving" industry (*j*) to the overall economy. Therefore, the first potential problem can be solved by using the ECBWs. However, the second problem is still a limitation of this study.

Specifically, the issue is that input coefficients are based on monetary values (dollars of input) rather than activity levels *per se* (e.g., vehicle-miles traveled, or quantity of information communicated). So the indication, for example, that it requires $x of commodity i (say transportation) to produce one dollar of output for industry j, does not say anything directly about the level of activity (say vehicle-miles traveled) involved for commodity i. This is unfortunate, since the interest of transportation planners, for example, is more in measures of actual transportation activity (i.e. reducing physical congestion on the network) than in economic measures. To the extent that dollars per unit of activity changes over time, simply looking at dollars can be misleading. For example, an industry spending similar amounts of money on telecommunications and transportation inputs over time may be obtaining increasingly higher "quantities" of telecommunications than of transportation, if the unit price of telecommunications is falling relative to that of transportation (as some evidence suggests that it is).

A second important limitation of this study is that the Spearman correlation is strictly a measure of association, and does not speak directly to true causality. That is, just knowing that the amounts of communications and transportation inputs demanded tend to be high or low together, does not say anything about whether one actually *causes* the need for the other, or whether there is some third variable operating more or less separately on both. Nevertheless, even identifying associations, especially any that appear to be stable across a number of years of major change in the communications industry, will be of interest, and of course such associations are at least a necessary, if not a sufficient, condition to establish causality.

Despite these limitations, this study has provided new insight into the long-term relationships between telecommunications and travel, particularly for industry. These results are of interest (among others) to policymakers and planners who are considering, or may consider, telecommunications as a transportation demand management policy tool.

# CHAPTER 6. CONCLUSIONS AND DIRECTIONS FOR FURTHER RESEARCH

This study applied input-output analysis (Leontief, 1936) to analyze the relationship between transportation and communications as industrial inputs in the U.S. Generally, input-output analysis offers a static view of the structural relationships, expressed purely in monetary terms, among the different sectors of an economy for a certain period of time. We analyzed correlations between transportation and communications using the input coefficients of transportation and communications in the input-output table (direct coefficient matrix). Positive correlation coefficients indicate complementarity: industries that require a lot of transportation inputs also tend to require a lot of communications inputs, and conversely. Negative correlation coefficients imply substitution.

Ten benchmark I-O accounts (between 1947 and 1997, inclusive) were collected, which are prepared using the most detailed data sources available, generally the economic censuses. Trying to find the best balance between highly disaggregated industry classifications (which may exhibit a lot of random noise that would obscure the patterns of interest) and highly aggregated ones (which contain such a small number of cases that it may also be hard to identify underlying relationships), we created four scenarios reflecting different levels of aggregation across sub-industries. Scenario 1 is the most disaggregate level (containing 79-131 categories, depending on year), while Scenario 4 is the most aggregate categorization, containing just the nine top-level industries. We analyzed correlations for five selected pairs of transportation and communications industry categories: the manufacturing pair (i.e., transportation manufacturing correlated with communications manufacturing), the utilities pair, the two manufacturing-utilities pairs, and the overall pair (all transportation manufacturing and utilities correlated with all communications manufacturing and utilities).

In this study the Spearman correlation is used, which is a nonparametric correlation measure. Since the input-output coefficients are not normally distributed, the Pearson correlation coefficient is not strictly appropriate. Using Spearman correlations, we conducted a cross-sectional analysis for each time period, and compared results across time based on the five sets of correlations between transportation and communications. Thus, 200 correlation coefficients in all are computed in this study.

In Chapter 5 we provided hypothetical examples of each type of relationship (substitution and complementarity for each combination of transportation and communications). Empirically, Table 5-4 and Figure 5-1 exhibited several interesting patterns. Since Scenario 1 is the most disaggregate level, and the other scenarios represent successively higher levels of aggregation, Scenario 1 is the scenario closest to the level of the individual actors. With that in mind, concentrating on Scenario 1 leads to the findings of predominant complementarity for the manufacturing pair (10×11) and substitution for the utilities pair (13×14). For the two manufacturing-utilities pairs, and the overall pair (all transportation manufacturing and utilities correlation with all communications manufacturing and utilities), we also see clear pictures of complementarity between transportation manufacturing and communications utilities (10×14) and substitution between transportation utilities and communications manufacturing (13×11) as well as transportation and communications overall (30×31) although the first and last of those results are somewhat weakly based on only four significant correlations out of 10.

This study has two main limitations. First, the input coefficients from the I-O accounts are calculated using the monetary values of each industry, and the relationships observed using a monetary basis may differ substantially from those based on measures of actual activity (such as volumes of communication or distance traveled). Second, we are identifying associations between communications and transportation inputs demanded, but that does not say anything about whether one actually causes the need for the other. However, the examples in Section 5.1 illustrate some ways in which a causal relationship could occur, so it is plausible to expect the observed associations to have at least some causal foundation. Nevertheless there are a number of fruitful directions for further research, including replication using total input coefficients, using I-O accounts for the year 2002 as soon as they become available, using disaggregate I-O accounts available from 1982 onward, and industry-specific correlations taken over time.

First, it is important to replicate this analysis for the total input coefficients, since the direct and total relationships could differ substantially. The total input coefficients were collected together with the direct input coefficients from 1947 to 1997 (ten benchmark years). Second, it is also 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 understand the recent trends in the relationships between transportation and communications. As we saw in Figure 5-1, there are some unclear and insignificant results especially for the latest years (1992 and 1997). For example, the 13×11 (transportation utilities and communications manufacturing) and 13×14 (transportation utilities and communications utilities) category pairs in Scenario 1 show correlation coefficients that are close to zero for those two years. Adding the results for 2002 will help us determine whether correlations are remaining flat (perhaps due to counteracting influences canceling), shifting from substitution to complementarity (as was apparently begun in 1987), or randomly bouncing back to negative (substitution).

Third, in view of our finding that results systematically differ by level of disaggregation (i.e., by scenario), it would be desirable to use the most disaggregate I-O accounts available, from 1982 onward. This study used the 82-131 industry categories as the most disaggregate classification (Scenario 1), which is available for all ten benchmark years (1947 through 1997). However, we can get even more detailed data sets, which include about 500 industry categories, from the BEA website as electronic files (text version) from 1982 onward. Although the disaggregate data sets include only four benchmark years (1982, 1987, 1992, and 1997), those data sets might allow us to analyze more accurate relationships than those of this study, by further reducing the ecological errors caused by category aggregation.

Finally, it is of interest to analyze industry-specific correlations taken over time. It is possible to calculate Spearman correlations across time for each industry, i.e. correlations over $t$ between $A_{Tjt}$ and $A_{Cjt}$, for each $j$ (see Figure 6-1). In doing so it is important to test for, and if necessary correct for, auto-correlation across time, although the multi-year span between benchmark tables may considerably attenuate any auto-correlations. The results would visually illustrate how the relationships between transportation and communications differ across industries at various levels of aggregation. In analyzing these industry-specific correlations, the Producer Price Index (PPI) should be applied to each year because the input-output coefficients are developed based on current monetary values. That is, one could create input-output coefficients in "constant dollars," converted from the "current dollar" input-output coefficients, because current dollars could mask substantial changes over time in the buying power for each input. For example, if $1 purchased much less transportation over time while $1 purchased much more communications (as is essentially the case), an apparently equal and stable ratio would hide sizable changes in the relative amounts of each input demanded over time.

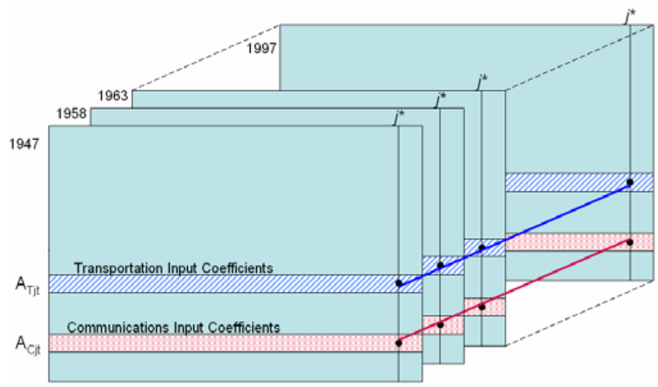



**Figure 6- 1. Schematic Showing the Industry-Specific Correlations between Transportation and Communications Taken Over Time**

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# APPENDICES

A. Detailed Description and Comparison for Classification of Industries in 1997

B. Comparison of Industry Categories by using NAICS and SIC for Unclear Categories for Classification of Industries in 1997 Benchmark I-O Accounts

C. Schematic Diagram for Spreadsheets in Excel (sample year 1992)

D. The ECBWs of Scenarios 2 through 4 for the Ten Benchmark Years (1947-1997)

E. Graphs of Spearman Correlations (1947-1997)

# *Appendix A. Detailed Description and Comparison for Classification of Industries in 1997*

| 1947 | 1972 | 1987 | Ind. Cat. | 1997 | 1997 | Title | Industry |
|---|---|---|---|---|---|---|---|
| 2 | 2 | 2 | 1 | 1110 | Crop production | Agriculture, Forestry, Fishing and Hunting | 1 |
| 1 | 1 | 1 | 1 | 1120 | Animal production | | 1 |
| 3* | 3* | 3* | 1 | 1130 | Forestry and logging | | 1 |
| 3* | 3* | 3* | 1 | 1140 | Fishing, hunting and trapping | | 1 |
| 4 | 4 | 4 | 1 | 1150 | Agriculture and forestry support activities | | 1 |
| 8 | 8 | 8 | 2 | 2110 | Oil and gas extraction | Mining | 2 |
| 7 | 7 | 7 | 2 | 2121 | Coal mining | | 2 |
| 5 and 6 | 5 and 6 | 5+6 | 2 | 2122 | Metal ores mining | | 2 |
| 9 | 9 | 9+10 | 2 | 2123 | Nonmetallic mineral mining and quarrying | | 2 |
| 7 and 8 | 7 and 8 | 7 and 8 | 2 | 2130 | Support activities for mining | | 2 |
| 68* | 68* | 68A | 5 | 2211 | Power generation and supply | Utilities | 2 |
| 68* | 68* | 68B | 5 | 2212 | Natural gas distribution | | 2 |
| 68* | 68* | 68C | 5 | 2213 | Water, sewage and other systems | | 2 |
| 11* | 11* | 11* | 3 | 2301 | New residential construction | Construction | 2 |
| 11* | 11* | 11* | 3 | 2302 | New nonresidential construction | | 2 |
| 12 | 12 | 12 | 3 | 2303 | Maintenance and repair construction | | 2 |
| 14* | 14* | 14* | 4 | 3110 | Food manufacturing | Manufacturing | 3 |
| 14* | 14* | 14* | 4 | 3121 | Beverage manufacturing | | 3 |
| 15 | 15 | 15 | 4 | 3122 | Tobacco manufacturing | | 3 |
| 16 | 16 | 16 | 4 | 3130 | Textile mills | | 3 |
| 17 and 19 | 17 and 19 | 17 and 19 | 4 | 3140 | Textile product mills | | 3 |
| 18 | 18 | 18 | 4 | 3150 | Apparel manufacturing | | 3 |
| 33 and 34 | 33 and 34 | 33+34 | 4 | 3160 | Leather and allied product manufacturing | | 3 |
| 20 and 21 | 20 and 21 | 20+21 | 4 | 3210 | Wood product manufacturing | | 3 |
| 24*and 25 | 24*and 25 | 24*and 25 | 4 | 3221 | Pulp, paper, and paperboard mills | | 3 |
| 24* | 24* | 24* | 4 | 3222 | Converted paper product manufacturing | | 3 |
| 26* | 26* | 26B | 4 | 3230 | Printing and related support activities | | 3 |
| 31 | 31 | 31 | 4 | 3240 | Petroleum and coal products manufacturing | | 3 |
| 27* | 27* | 27A* | 4 | 3251 | Basic chemical manufacturing | | 3 |
| 28 | 28 | 28 | 4 | 3252 | Resin, rubber, and artificial fibers manufacturing | | 3 |
| 27* | 27* | 27B | 4 | 3253 | Agricultural chemical manufacturing | | 3 |
| 29* | 29* | 29A | 4 | 3254 | Pharmaceutical and medicine manufacturing | | 3 |
| 30 | 30 | 30 | 4 | 3255 | Paint, coating, and adhesive manufacturing | | 3 |
| 29* | 29* | 29B | 4 | 3256 | Soap, cleaning compound, and toiletry manufacturing | | 3 |
| 27* | 27* | 27A* | 4 | 3259 | Other chemical product and preparation manufacturing | | 3 |
| 32 | 32 | 32 | 4 | 3260 | Plastics and rubber products manufacturing | | 3 |
| 36 | 36 | 36 | 4 | 3270 | Nonmetallic mineral product manufacturing | | 3 |
| 37* | 37* | 37* | 4 | 331A | Iron and steel mills and manufacturing from purchased steel | | 3 |
| 38 | 38 | 38 | 4 | 331B | Nonferrous metal production and processing | | 3 |
| 37* | 37* | 37* | 4 | 3315 | Foundries | | 3 |
| 41 | 41 | 41 | 4 | 3321 | Forging and stamping | | 3 |
| 42* | 42* | 42* | 4 | 3322 | Cutlery and handtool manufacturing | | 3 |
| 40* | 40* | 40* | 4 | 3323 | Architectural and structural metals manufacturing | | 3 |
| 39and 40* | 39and 40* | 39and 40* | 4 | 3324 | Boiler, tank, and shipping container manufacturing | | 3 |
| 13 | 13 | 13 | 4 | 332A | Ordnance and accessories manufacturing | | 3 |
| 42* | 42* | 42* | 4 | 332B | Other fabricated metal product manufacturing | | 3 |
| 44 and 45 | 44 and 45 | 44+45 | 4 | 3331 | Agriculture, construction, and mining machinery | | 3 |
| 48 | 48 | 48 | 4 | 3332 | Industrial machinery manufacturing | | 3 |
| 50 and52* | 50 and52* | 50 and52* | 4 | 3333 | Commercial and service industry machinery | | 3 |
| 52* | 52* | 52* | 4 | 3334 | HVAC and commercial refrigeration equipment | | 3 |
| 47 | 47 | 47 | 4 | 3335 | Metalworking machinery manufacturing | | 3 |
| 43 and49* | 43 and49* | 43 and49* | 4 | 3336 | Turbine and power transmission equipment manufacturing | | 3 |
| 46and 49* | 46and 49* | 46and 49* | 4 | 3339 | Other general purpose machinery manufacturing | | 3 |
| 51 | 51 | 51 | 20 | 3341 | Computer and peripheral equipment manufacturing | | 3 |
| 56 | 56 | 56 | 21 | 334A | Audio, video, and communications equipment manufacturing | | 3 |
| 57* | 57* | 57* | 4 | 3344 | Semiconductor and electronic component manufacturing | | 3 |
| 57* | 57* | 57* | 4 | 3345 | Electronic instrument manufacturing | | 3 |
| 58* | 58* | 58* | 4 | 3346 | Magnetic media manufacturing and reproducing | | 3 |
| 55 | 55 | 55 | 4 | 3351 | Electric lighting equipment manufacturing | | 3 |
| 54 | 54 | 54 | 4 | 3352 | Household appliance manufacturing | | 3 |
| 53 | 53 | 53 | 4 | 3353 | Electrical equipment manufacturing | | 3 |
| 58* | 58* | 58* | 4 | 3359 | Other electrical equipment and component machinery | | 3 |
| 59* | 59* | 59A | 16 | 3361 | Motor vehicle manufacturing | | 3 |
| 59* | 59* | 59B | 17 | 336A | Motor vehicle body, trailer, and parts manufacturing | | 3 |
| 60* | 60* | 60* | 18 | 3364 | Aerospace product and parts manufacturing | | 3 |
| 61 | 61 | 61 | 19 | 336B | Other transportation equipment manufacturing | | 3 |
| 22 and 23 | 22 and 23 | 22+23 | 4 | 3370 | Furniture and related product manufacturing | | 3 |
| 62 and 63 | 62 and 63 | 62 and 63 | 4 | 3391 | Medical equipment and supplies manufacturing | | 3 |
| 64 | 64 | 64 | 4 | 3399 | Other miscellaneous manufacturing | | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 69* | 69* | 69A | 6 | 4200 | Wholesale trade | Wholesale Trade | 4 |
| 69* | 69* | 69B | 6 | 4A00 | Retail trade | Retail Trade | 4 |
| 65* | 65* | 65D | 25 | 4810 | Air transportation | Transportation and Warehousing, Excluding Postal Service | 4 |
| 65* | 65* | 65A* | 22A | 4820 | Rail transportation | | 4 |
| 65* | 65* | 65C | 24 | 4830 | Water transportation | | 4 |
| 65* | 65* | 65B* | 23A | 4840 | Truck transportation | | 4 |
| 65* | 65* | 65A* | 22B | 4850 | Transit and ground passenger transportation | | 4 |
| 65* | 65* | 65E* | 26A | 4860 | Pipeline transportation | | 4 |
| 65* | 65* | 65A* | 26B | 48A0 | Scenic and sightseeing transportation and support activities for transportation | | 4 |
| 65* | 65* | 65E* | 26C | 4920 | Couriers and messengers | | 4 |
| 65* | 65* | 65B* | 23B | 4930 | Warehousing and storage | | 4 |
| 26* | 26* | 26A | 4 | 5111 | Newspaper, book, and directory publishers | Information | 5 |
| 73* | 73* | 73A* | 8 | 5112 | Software publishers | | 5 |
| 76* | 76* | 76* | 8 | 5120 | Motion picture and sound recording industries | | 5 |
| 67* | 67* | 67* | 28A | 5131 | Radio and television broadcasting | | 5 |
| 67* | 67* | 67* | 28B | 5132 | Cable networks and program distribution | | 5 |
| 66* | 66* | 66* | 27A | 5133 | Telecommunications | | 5 |
| 73* | 73* | 73C* | 8 | 5141 | Information services | | 5 |
| 73* | 73* | 73A* | 8 | 5142 | Data processing services | | 5 |
| 70* | 70* | 70A* | 7 | 52A0 | Monetary authorities, credit intermediation and related activities | Finance and Insurance | 5 |
| 70* | 70* | 70A* | 7 | 5230 | Securities, commodity contracts, investments | | 5 |
| 70* | 70* | 70B | 7 | 5240 | Insurance carriers and related activities | | 5 |
| 70* | 70* | 70A* | 7 | 5250 | Funds, trusts, and other financial vehicles | | 5 |
| 71* | 71* | 71B | 7 | 5310 | Real estate | Real Estate and Rental and Leasing | 5 |
| 71* | 71* | 71A | 7 | S008 | Owner-occupied dwellings | | S |
| 75* | 75* | 75* | 8 | 5321 | Automotive equipment rental and leasing | | 5 |
| 76* | 76* | 76* | 8 | 532A | Consumer goods and general rental centers | | 5 |
| 73* | 73* | 73C* | 8 | 5324 | Machinery and equipment rental and leasing | | 5 |
| 70* | 70* | 70A* | 7 | 5330 | Lessors of nonfinancial intangible assets | | 5 |
| 73* | 73* | 73B* | 8 | 5411 | Legal services | Professional and Technical Services | 5 |
| 73* | 73* | 73B* | 8 | 5412 | Accounting and bookkeeping services | | 5 |
| 73* | 73* | 73B* | 8 | 5413 | Architectural and engineering services | | 5 |
| 73* | 73* | 73C* | 8 | 5414 | Specialized design services | | 5 |
| 73* | 73* | 73A* | 8 | 5415 | Computer systems design and related services | | 5 |
| 73* | 73* | 73C* | 8 | 5416 | Management and technical consulting services | | 5 |
| 74 | 73* | 73C* | 8 | 5417 | Scientific research and development services | | 5 |
| 73* | 73* | 73D | 8 | 5418 | Advertising and related services | | 5 |
| 73* | 73* | 73C* | 8 | 5419 | Other professional and technical services | | 5 |
| 73* | 73* | 73C* | 8 | 5500 | Management of companies and enterprises | Management of Companies and Enterprises | 5 |
| 73* | 73* | 73C* | 8 | 5613 | Employment services | | 5 |
| 65* | 65* | 65E* | 26D | 5615 | Travel arrangement and reservation services | | 5 |
| 73* | 73* | 73C* | 8 | 561A | All other administrative and support services | | 5 |
| 68 | 68 | 68C | 15 | 5620 | Waste management and remediation services | | 5 |
| 77* | 77* | 77B* | 8 | 6100 | Educational services | Educational Services | 6 |
| 77* | 77* | 77A* | 8 | 6210 | Ambulatory health care services | Health Care and Social Assistance | 6 |
| 77* | 77* | 77A* | 8 | 6220 | Hospitals | | 6 |
| 77* | 77* | 77A* | 8 | 6230 | Nursing and residential care facilities | | 6 |
| 77* | 77* | 77B* | 8 | 6240 | Social assistance | | 6 |
| 76* | 76* | 76* | 8 | 71A0 | Performing arts, spectator sports, museums, zoos, and parks | Arts, Entertainment, and Recreation | 7 |
| 76* | 76* | 76* | 8 | 7130 | Amusements, gambling, and recreation | | 7 |
| 72* | 72* | 72A | 8 | 7210 | Accommodation | Accommodation and Food Services | 7 |
| 69* | 74 | 74 | 8 | 7220 | Food services and drinking places | | 7 |
| 75* | 75* | 75* | 8 | 8111 | Automotive repair and maintenance | Other Services, Except Public Administration | 8 |
| 72* | 72* | 72B* | 8 | 811A | Electronic, commercial, and household goods repair | | 8 |
| 72* | 72* | 72B* | 8 | 8120 | Personal and laundry services | | 8 |
| 77* | 77* | 77B* | 8 | 813A | Religious, grantmaking and giving, and social advocacy organizations | | 8 |
| 77* | 77* | 77B* | 8 | 813B | Civic, social, professional and similar organizations | | 8 |
| 86 | 84 | 84 | 9 | 8140 | Private households | | 8 |
| 78 | 78 | 78 | 9 | S001 | Federal Government enterprises | Government Industries | S |
| 79* | 79* | 79* | 9 | S002 | State and local government enterprises | | S |
| 84 | 82 | 82 | 9 | S005 | General government industry | | S |
| 80* | 80 | 80 | 9 | S003 | Noncomparable imports | Special Industries | S |
| 83 | 81 | 81 | 9 | S004 | Scrap, used, and secondhand goods | | S |
| 85 | 83 | 83 | 9 | S006 | Rest of the world adjustment to final uses | | S |
| 82# | 85 | 85 | 9 | S007 | Inventory valuation adjustment | | S |
| | 88 | 88 | | V001 | Compensation of employees | Value Added | V |
| | 89 | 89 | | V002 | Indirect business tax and nontax liability | | V |
| | 90 | 90 | | V003 | Other value added | | V |
| | 91 | 91 | | F010 | Personal consumption expenditures | Final Uses | F |
| | 92 | 92 | | F020 | Private fixed investment | | F |
| | 93 | 93 | | F030 | Change in private inventories | | F |
| | 94 | 94 | | F040 | Exports of goods and services | | F |
| 80* | 95 | 95 | | F050 | Imports of goods and services | | F |
| | 96* | 96* | | F06C | Federal government consumption expenditures, national defense | | F |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 96* | 96* | | F06I | Federal government gross investment, national defense | | F |
| | 97* | 97* | | F07C | Federal government consumption expenditures, nondefense | | F |
| | 97* | 97* | | F07I | Federal government gross investment, nondefense | | F |
| | 98* | 98* | | F08C | State and local government consumption expenditure, education | | F |
| | 98* | 98* | | F08I | State and local government gross investment, education | | F |
| | 99* | 99* | | F09C | State and local government consumption expenditures, other | | F |
| | 99* | 99* | | F09I | State and local government gross investment, other | | F |

Note: 1) Column "Industry" means the first digit I-O industry number in the 1997 benchmark Input-Output Accounts
"S" explains government or special industries
"V" explains value added
"F" explains final uses

2) In 1987, 68A, 68B, and 68C do not have corresponding industry classification in 1997
68A: Electric services (utilities)
68B: Gas production and distribution (utilities)
68C: Water and sanitary services

3) In 1972, 10 and 68 do not have corresponding industry classification in 1997

4) In 1967, 10, 68, 81, and 82 do not have corresponding industry classification in 1997

5) Shaded area means that there is no obvious corresponding industry

6) *****: This category also exists in the other cell within the column.

7) **#**: There is no correspondence with the industry category in 1997, but it might be included in this industry category.

8) In the industry category number, **"+"** is included in the original I-O number in 1987. The **"and"** means both two industries are correspondent with this industry category in 1997.

*Appendix B. Comparison of Industry Categories by using NAICS and SIC for Unclear Categories for Classification of Industries in 1997 Benchmark I-O Accounts*

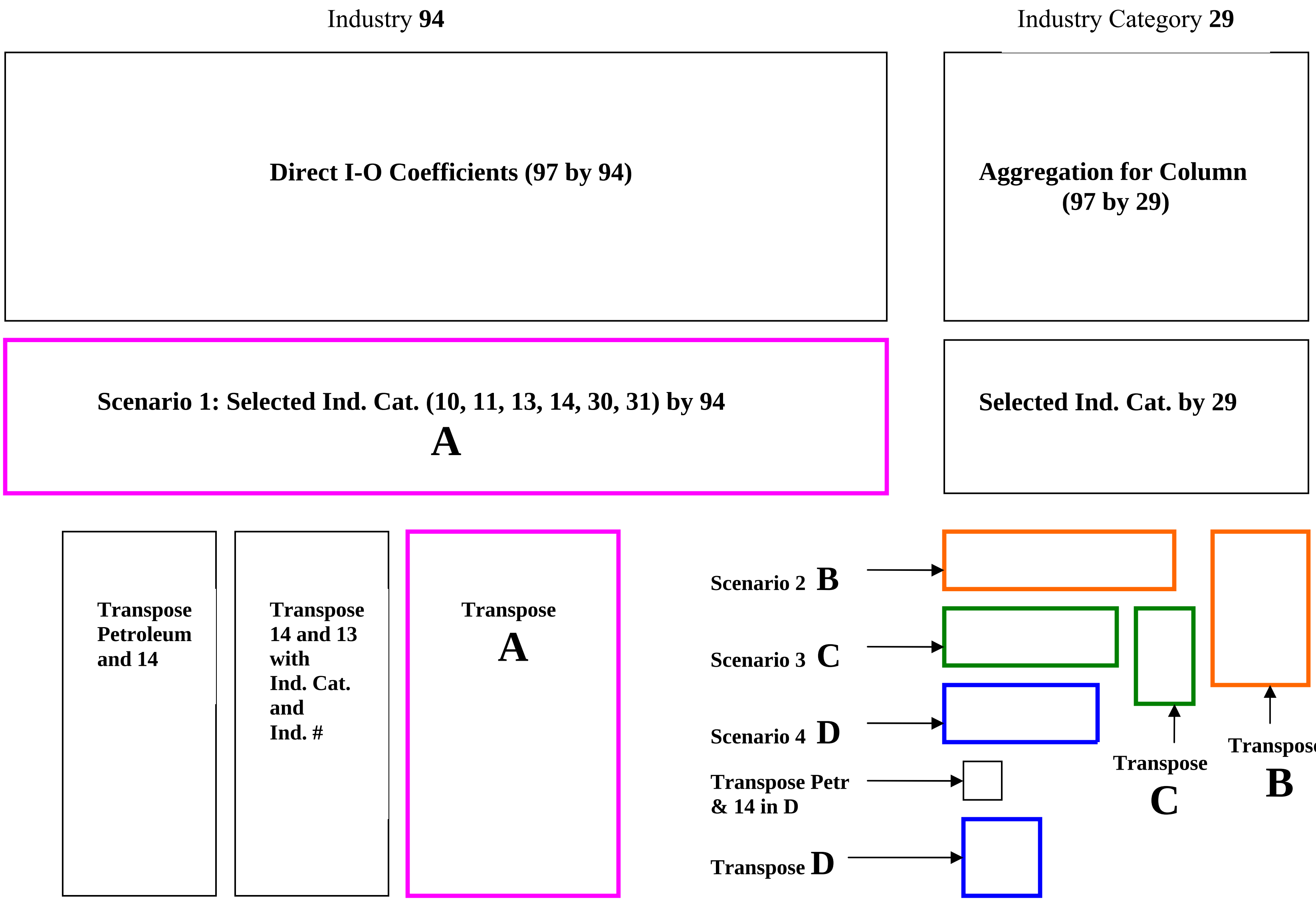
| | |
|---|---|
| (pink) | : Need to Change |
| Comp. (yellow) | : Comparable between NAICS and SIC |

| Seq. # | 1997 | NAICS | Comparability | SIC | 1992 | Current Ind. Cat. | Proposed Ind. Cat. |
|---|---|---|---|---|---|---|---|
| 1 | 2130 | 213111 | Comp. | 1381 | 8 | 2 | 2 |
| | | 213112 | Almost Comp. | 1382, 1389 | 8 | | |
| | | 213113 | Comp. | 1241 | 7 | | |
| | | 213114 | Almost Comp. | 1081 | 5+6 | | |
| | | 213115 | Not Comp. | 1481 | 9+10 | | |
| 2 | 5112 | 511210 | Comp. | 7372 | 73A | 4 | 8 |
| 3 | 5141 | 519110 | N/A | 7383 | 73C | 27B | 8 |
| | | 519120 | N/A | 7829, 8231 | 76, 77B | | |
| | | 519190 | N/A | 7389 | | | |
| 4 | 532A | 532210 | Not Comp. | 7359 | | | |
| | | 532220 | Not Comp. | 7299, 7819 | | | |
| | | 532230 | Comp. | 7841 | 76 | 8 | 8 |
| | | 532291 | Not Comp. | 7352 | | | |
| | | 532292 | Not Comp. | 7999 | | | |
| | | 532299 | Not Comp. | 7359 | | | |
| | | 532310 | Not Comp. | 7359 | | | |
| 5 | 5330 | 533110 | Almost Comp. | 6792, 6794 | 70A | 8 | 7 |
| 6 | 5415 | 541511 | Comp. | 7371 | 73A | 8 | 8 |
| | | 541512 | Not Comp. | 7373, 7379 | 73 (1947) | | |
| | | 541513 | Comp. | 7376 | 73A | | |
| | | 541519 | Not Comp. | 7379 | | | |
| 7 | 5417 | 541710 | Comp. | 3721, 3724 | 60 | 8 | 8 |
| | | | | 3728, 3761 | | | |
| | | | | 3764, 3769 | | | |
| | | | | 8731, 8733 | 73C | | |
| 8 | 5615 | 561510 | Comp. | 4724 | 65E | 26D | 26D |
| | | 561520 | Comp. | 4725 | | | |
| | | 561591 | Not Comp. | 7389 | | | |
| | | 561599 | Not Comp. | 4729, 7389 | | | |
| | | | | 7922, 7999 | | | |
| | | | | 8699 | | | |
| 9 | 5620 | 562111 | Not Comp. | 4212 | 65B | 9 | 15 |
| | | 562112 | Not Comp. | 4212 | | | |
| | | 562119 | Not Comp. | 4212 | | | |
| | | 562211 | Not Comp. | 4953 | 68C | | |
| | | 562212 | Not Comp. | 4953 | | | |
| | | 562213 | Not Comp. | 4953 | | | |
| | | 562219 | Not Comp. | 4953 | | | |
| | | 562910 | Not Comp. | 1799, 4959 | | | |
| | | 562920 | Not Comp. | 4953 | | | |
| | | 562991 | Not Comp. | 7359, 7699 | 73C | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 562998 | Not Comp. | 4959, 7699 | | | |
| 10 | 7220 | 722110 | Not Comp. | 5812 | 74 | 8 | 8 |
| | | 722211 | Not Comp. | 5812 | 69 (1947) | | |
| | | 722212 | Not Comp. | 5812 | | | |
| | | 722213 | Not Comp. | 5461, 5812 | | | |
| | | 722310 | Not Comp. | 4789, 5812 | | | |
| | | 722320 | Not Comp. | 5812 | | | |
| | | 722330 | Not Comp. | 5963 | | | |
| | | 722410 | Comp. | 5813 | | | |
| 11 | S003 | N/A | | | | 9 | 9 |
| | S007 | N/A | | | | 9 | 9 |

Source: http://landview.census.gov/epcd/naics02/N02TOS87.HTM
Correspondence Tables: 2002 NAICS Matched to 1987 SIC

*Appendix C. Schematic Diagram for Spreadsheets in Excel (sample year 1992)*



## *Appendix D. The ECBWs of Scenarios 2 through 4 for the Ten Benchmark Years (1947-1997)*

As mentioned in Chapter 4, there are four scenarios according to the aggregation level of industry classifications. The following tables present the ECBWs for Scenarios 2 through 4 across the corresponding industry categories (the ECBWs for Scenario 1 are omitted due to space restrictions). The industry categories for each scenario are explained in Table 4-6, and the structure of the ECBWs is the same as that of each scenario since the ECBWs are applied to each I-O coefficient of the corresponding industry. The first row of each scenario contains the numeric label of each industry category. The values in the second rows of each scenario in 1947 are calculated by adding the ECBWs of Scenario 1 across the industries comprising each cell (the sum of the ECBWs is 80). The values of the third rows of each scenario are recalculated by using the second rows, so that the sum of the values of the third rows is 18, 13, and 9, respectively (for S2, S3, and S4) in 1947. This has the effect of calculating the correlation coefficients on the appropriate sample size (e.g., it should be 9 for S4, not 80), while weighting each industry in the correlation proportionally to its overall monetary contribution to the economy.

**1947**

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S2 | 1 | 2 | 3 | 16+17 | 18 | 19 | 20 | 21 | 22 | 12 | 23~27 | 28 | 29 | 15 | 6 | 7 | 8 | 9 | | Sum |
| | 14.55579 | 3.16608 | 2.56260 | 1.69144 | 0.20103 | 0.20173 | 1.70144 | 0.03721 | 0.22663 | 31.92199 | 4.39842 | 0.53855 | 0.14275 | 1.33142 | 4.50838 | 5.34548 | 4.27083 | 3.19825 | | 80.00000 |
| | 3.2750519 | 0.712368 | 0.576585 | 0.380573 | 0.0452307 | 0.0453885 | 0.382824 | 0.0083711 | 0.0509912 | 7.1824471 | 0.9896451 | 0.1211741 | 0.03211859 | 0.299569 | 1.014386 | 1.202733 | 0.960937 | 0.719606 | | 18.00000 |
| S3 | 1 | 2 | 3 | 10 | 11 | 12 | 13 | 14 | 15 | 6 | 7 | 8 | 9 | | | | | | | |
| | 14.55579 | 3.16608 | 2.56260 | 3.79563 | 0.26383 | 31.92199 | 4.39842 | 0.68130 | 1.33142 | 4.50838 | 5.34548 | 4.27083 | 3.19825 | | | | | | | 80.00000 |
| | 2.3653152 | 0.514488 | 0.416423 | 0.6167896 | 0.0428728 | 5.1873229 | 0.7147437 | 0.1107114 | 0.2163553 | 0.7326121 | 0.8686405 | 0.6940102 | 0.51971556 | | | | | | | 13.00000 |
| S4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | | |
| | 14.55579 | 3.16608 | 2.56260 | 35.98145 | 6.41114 | 4.50838 | 5.34548 | 4.27083 | 3.19825 | | | | | | | | | | | 80.00000 |
| | 1.6375259 | 0.356184 | 0.288293 | 4.0479129 | 0.7212534 | 0.507193 | 0.6013665 | 0.4804686 | 0.3598031 | | | | | | | | | | | 9.00000 |

**1958**

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S2 | 1 | 2 | 3 | 16+17 | 18 | 19 | 20 | 21 | 22 | 12 | 23~27 | 28 | 29 | 15 | 6 | 7 | 8 | 9 | | Sum |
| | 8.13332 | 3.22235 | 2.30181 | 1.76660 | 1.02921 | 0.17779 | 1.693233 | 0.16633 | 0.38607 | 32.31022 | 3.81744 | 0.84976 | 0.28461 | 2.09945 | 5.10502 | 6.39647 | 5.73707 | 5.52324 | | 81.00000 |
| | 1.8074047 | 0.716079 | 0.511514 | 0.3925784 | 0.2287131 | 0.0395084 | 0.376274 | 0.0369621 | 0.0857931 | 7.1800487 | 0.8483208 | 0.1888352 | 0.06324623 | 0.466544 | 1.134448 | 1.421438 | 1.274904 | 1.227388 | | 18.00000 |
| S3 | 1 | 2 | 3 | 10 | 11 | 12 | 13 | 14 | 15 | 6 | 7 | 8 | 9 | | | | | | | |
| | 8.13332 | 3.22235 | 2.30181 | 4.66683 | 0.55240 | 32.31022 | 3.81744 | 1.13437 | 2.09945 | 5.10502 | 6.39647 | 5.73707 | 5.52324 | | | | | | | 81.00000 |
| | 1.3053479 | 0.517168 | 0.369427 | 0.7489978 | 0.0886565 | 5.1855907 | 0.6126762 | 0.1820588 | 0.3369482 | 0.8193239 | 1.0265944 | 0.9207642 | 0.88644655 | | | | | | | 13.00000 |
| S4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | | |
| | 8.13332 | 3.22235 | 2.30181 | 37.52945 | 7.05126 | 5.10502 | 6.39647 | 5.73707 | 5.52324 | | | | | | | | | | | 81.00000 |
| | 0.9037024 | 0.358039 | 0.255757 | 4.1699389 | 0.7834729 | 0.5672242 | 0.7107192 | 0.6374522 | 0.6136938 | | | | | | | | | | | 9.00000 |

**1963**

| S2 | 1 | 2 | 3 | 16+17 | 18 | 19 | 20 | 21 | 22 | 12 | 23~27 | 28 | 29 | 15 | 6 | 7 | 8 | 9 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7.12198 | 2.87381 | 2.18076 | 2.29852 | 0.74657 | 0.15896 | 1.7211765 | 0.19137 | 0.45577 | 32.75016 | 3.59281 | 0.98839 | 0.33201 | 2.51467 | 4.70189 | 6.48539 | 6.00131 | 5.88444 | 81.00000 |
| | 1.582662 | 0.638624 | 0.484614 | 0.5107821 | 0.1659048 | 0.0353252 | 0.3824837 | 0.0425272 | 0.1012831 | 7.2778133 | 0.7984025 | 0.21964215 | 0.073779 | 0.558817 | 1.044864 | 1.441198 | 1.333625 | 1.307653 | 18.00000 |
| S3 | 1 | 2 | 3 | 10 | 11 | 12 | 13 | 14 | 15 | 6 | 7 | 8 | 9 | | | | | | |
| | 7.12198 | 2.87381 | 2.18076 | 4.92523 | 0.64715 | 32.75016 | 3.59281 | 1.32039 | 2.51467 | 4.70189 | 6.48539 | 6.00131 | 5.88444 | | | | | | 81.00000 |
| | 1.143034 | 0.461229 | 0.349999 | 0.7904691 | 0.1038629 | 5.2561985 | 0.576624 | 0.2119152 | 0.4035897 | 0.7546243 | 1.0408652 | 0.96317391 | 0.944416 | | | | | | 13.00000 |
| S4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | |
| | 7.12198 | 2.87381 | 2.18076 | 38.32254 | 7.42788 | 4.70189 | 6.48539 | 6.00131 | 5.88444 | | | | | | | | | | 81.00000 |
| | 0.791331 | 0.319312 | 0.242307 | 4.2580596 | 0.82532 | 0.5224322 | 0.720599 | 0.6668127 | 0.6538264 | | | | | | | | | | 9.00000 |

**1967**

| S2 | 1 | 2 | 3 | 16+17 | 18 | 19 | 20 | 21 | 22 | 12 | 23~27 | 28 | 29 | 15 | 6 | 7 | 8 | 9 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6.08712 | 2.62595 | 1.97672 | 1.72740 | 0.80416 | 0.14924 | 1.575593 | 0.18532 | 0.40314 | 33.02791 | 3.59376 | 1.03182 | 0.35477 | 2.38713 | 4.75314 | 6.78404 | 7.20964 | 6.32315 | 81.00000 |
| | 1.352693 | 0.583545 | 0.439272 | 0.3838666 | 0.1787025 | 0.0331638 | 0.3501318 | 0.0411818 | 0.0895871 | 7.3395364 | 0.7986132 | 0.22929225 | 0.078839 | 0.530473 | 1.056254 | 1.507565 | 1.602141 | 1.405144 | 18.00000 |
| S3 | 1 | 2 | 3 | 10 | 11 | 12 | 13 | 14 | 15 | 6 | 7 | 8 | 9 | | | | | | |
| | 6.08712 | 2.62595 | 1.97672 | 4.25639 | 0.58846 | 33.02791 | 3.59376 | 1.38659 | 2.38713 | 4.75314 | 6.78404 | 7.20964 | 6.32315 | | | | | | 81.00000 |
| | 0.976945 | 0.421449 | 0.317252 | 0.6831245 | 0.0944441 | 5.3007763 | 0.5767762 | 0.2225389 | 0.3831191 | 0.7628498 | 1.0887969 | 1.15710214 | 1.014826 | | | | | | 13.00000 |
| S4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | |
| | 6.08712 | 2.62595 | 1.97672 | 37.87276 | 7.36747 | 4.75314 | 6.78404 | 7.20964 | 6.32315 | | | | | | | | | | 81.00000 |
| | 0.676346 | 0.291772 | 0.219636 | 4.2080849 | 0.8186083 | 0.5281268 | 0.7537824 | 0.8010707 | 0.7025721 | | | | | | | | | | 9.00000 |

**1972**

| S2 | 1 | 2 | 3 | 16+17 | 18 | 19 | 20 | 21 | 22 | 12 | 23~27 | 28 | 29 | 15 | 6 | 7 | 8 | 9 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3.37409 | 1.22118 | 6.67125 | 2.62103 | 0.68466 | 0.51393 | 1.2635746 | 0.32376 | 0.72223 | 24.46233 | 3.00527 | 1.26856 | 0.18137 | 2.01539 | 8.69620 | 10.14633 | 10.84088 | 0.98796 | 79.00000 |
| | 0.768779 | 0.278243 | 1.5200323 | 0.5971968 | 0.1559975 | 0.1170988 | 0.2879031 | 0.0737682 | 0.1645592 | 5.573696 | 0.6847462 | 0.28903854 | 0.041325 | 0.459202 | 1.981413 | 2.311823 | 2.470073 | 0.225105 | 18.00000 |
| S3 | 1 | 2 | 3 | 10 | 11 | 12 | 13 | 14 | 15 | 6 | 7 | 8 | 9 | | | | | | |
| | 3.37409 | 1.22118 | 6.67125 | 5.08319 | 1.04599 | 24.46233 | 3.00527 | 1.44993 | 2.01539 | 8.69620 | 10.14633 | 10.84088 | 0.98796 | | | | | | 79.00000 |
| | 0.55523 | 0.200953 | 1.0978011 | 0.836475 | 0.1721254 | 4.0254471 | 0.4945389 | 0.2385961 | 0.3316457 | 1.4310208 | 1.66965 | 1.78394169 | 0.162576 | | | | | | 13.00000 |
| S4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | |
| | 3.37409 | 1.22118 | 6.67125 | 30.59152 | 6.47059 | 8.69620 | 10.14633 | 10.84088 | 0.98796 | | | | | | | | | | 79.00000 |
| | 0.38439 | 0.139121 | 0.7600162 | 3.4851098 | 0.7371559 | 0.9907067 | 1.1559115 | 1.2350366 | 0.1125524 | | | | | | | | | | 9.00000 |

**1977**

| S2 | 1 | 2 | 3 | 16+17 | 18 | 19 | 20 | 21 | 22 | 12 | 23~27 | 28 | 29 | 15 | 6 | 7 | 8 | 9 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.96982 | 1.78723 | 6.05434 | 2.69547 | 0.60412 | 0.49565 | 2.265103 | 0.36172 | 0.66143 | 23.95146 | 2.89073 | 1.21087 | 0.19400 | 2.41858 | 8.80501 | 9.27983 | 11.38172 | 0.97292 | 79.00000 |
| | 0.676667 | 0.407217 | 1.3794694 | 0.6141581 | 0.1376474 | 0.1129318 | 0.5160994 | 0.0824183 | 0.1507045 | 5.4572941 | 0.6586471 | 0.27589492 | 0.044202 | 0.55107 | 2.006204 | 2.114392 | 2.593304 | 0.221678 | 18.00000 |
| S3 | 1 | 2 | 3 | 10 | 11 | 12 | 13 | 14 | 15 | 6 | 7 | 8 | 9 | | | | | | |
| | 2.96982 | 1.78723 | 6.05434 | 6.06034 | 1.02315 | 23.95146 | 2.89073 | 1.40487 | 2.41858 | 8.80501 | 9.27983 | 11.38172 | 0.97292 | | | | | | 79.00000 |
| | 0.488704 | 0.294101 | 0.9962834 | 0.9972709 | 0.1683665 | 3.9413791 | 0.4756896 | 0.2311811 | 0.3979948 | 1.4489254 | 1.5270612 | 1.87294156 | 0.160101 | | | | | | 13.00000 |
| S4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | |
| | 2.96982 | 1.78723 | 6.05434 | 31.03495 | 6.71418 | 8.80501 | 9.27983 | 11.38172 | 0.97292 | | | | | | | | | | 79.00000 |
| | 0.338334 | 0.203609 | 0.6897347 | 3.5356268 | 0.7649069 | 1.0031022 | 1.0571962 | 1.2966519 | 0.1108391 | | | | | | | | | | 9.00000 |

**1982**

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S2 | 1 | 2 | 3 | 16+17 | 18 | 19 | 20 | 21 | 22 | 12 | 23~27 | 28 | 29 | 15 | 6 | 7 | 8 | 9 | Sum |
| | 2.77774 | 2.73825 | 6.23796 | 1.58143 | 0.83078 | 0.37765 | 2.9385815 | 0.57856 | 0.75819 | 20.46179 | 2.79234 | 1.36634 | 0.22341 | 3.14732 | 8.20318 | 10.17642 | 12.70617 | 1.10389 | 79.00000 |
| | 0.632903 | 0.623904 | 1.4213066 | 0.3603255 | 0.1892923 | 0.0860478 | 0.6695502 | 0.1318234 | 0.1727532 | 4.662179 | 0.6362292 | 0.31131724 | 0.050903 | 0.717111 | 1.869079 | 2.318679 | 2.895078 | 0.251519 | 18.00000 |
| S3 | 1 | 2 | 3 | 10 | 11 | 12 | 13 | 14 | 15 | 6 | 7 | 8 | 9 | | | | | | |
| | 2.77774 | 2.73825 | 6.23796 | 5.72845 | 1.33675 | 20.46179 | 2.79234 | 1.58974 | 3.14732 | 8.20318 | 10.17642 | 12.70617 | 1.10389 | | | | | | 79.00000 |
| | 0.457096 | 0.450597 | 1.0264992 | 0.9426558 | 0.219972 | 3.3671293 | 0.4594988 | 0.2616036 | 0.5179132 | 1.3498906 | 1.6746013 | 2.09088944 | 0.181653 | | | | | | 13.00000 |
| S4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | |
| | 2.77774 | 2.73825 | 6.23796 | 27.52699 | 7.52940 | 8.20318 | 10.17642 | 12.70617 | 1.10389 | | | | | | | | | | 79.00000 |
| | 0.316451 | 0.311952 | 0.7106533 | 3.1359857 | 0.85778 | 0.9345396 | 1.1593394 | 1.4475388 | 0.1257597 | | | | | | | | | | 9.00000 |

## 1987

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S2 | 1 | 2 | 3 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 12 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 15 | 6 | 7 | 8 | 9 | | Sum |
| | 2.31940 | 1.47265 | 7.03969 | 1.52571 | 0.78485 | 0.93429 | 0.27396 | 1.56844 | 0.63501 | 0.46300 | 21.82698 | 0.49439 | 1.32071 | 0.27363 | 0.86746 | 0.29473 | 1.83300 | 0.33441 | 2.40243 | 9.60650 | 13.25183 | 16.97481 | 6.50210 | | 93.00000 |
| | 0.573616 | 0.364204 | 1.741 | 0.377325 | 0.194102 | 0.231062 | 0.0677538 | 0.387893 | 0.157045 | 0.114506 | 5.398069 | 0.122267 | 0.32663 | 0.0676719 | 0.21453 | 0.07289 | 0.45332 | 0.0827 | 0.59415 | 2.3758 | 3.27733 | 4.19807 | 1.60805 | | 23.00000 |
| S3 | 1 | 2 | 3 | 10 | 11 | 12 | 13 | 14 | 15 | 6 | 7 | 8 | 9 | | | | | | | | | | | | |
| | 2.31940 | 1.47265 | 7.03969 | 5.08725 | 1.09801 | 21.82698 | 3.25093 | 2.16741 | 2.40243 | 9.60650 | 13.25183 | 16.97481 | 6.50210 | | | | | | | | | | | | 93.00000 |
| | 0.324217 | 0.205854 | 0.984043 | 0.71112 | 0.153486 | 3.051083 | 0.4544306 | 0.302972 | 0.335824 | 1.342844 | 1.852406 | 2.372823 | 0.9089 | | | | | | | | | | | | 13.00000 |
| S4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | | | | | | | |
| | 2.31940 | 1.47265 | 7.03969 | 28.01223 | 7.82077 | 9.60650 | 13.25183 | 16.97481 | 6.50210 | | | | | | | | | | | | | | | | 93.00000 |
| | 0.224458 | 0.142515 | 0.681261 | 2.710861 | 0.756849 | 0.929662 | 1.2824352 | 1.642724 | 0.629236 | | | | | | | | | | | | | | | | 9.00000 |

## 1992

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S2 | 1 | 2 | 3 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 12 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 15 | 6 | 7 | 8 | 9 | | Sum |
| | 2.04225 | 1.34668 | 5.83755 | 1.29531 | 0.68973 | 0.87399 | 0.25779 | 1.25209 | 0.54930 | 0.44817 | 19.99442 | 0.47910 | 1.43464 | 0.27876 | 0.80896 | 0.28887 | 1.78817 | 0.25228 | 2.43386 | 9.37927 | 14.21926 | 19.14154 | 7.90798 | | 93.00000 |
| | 0.505073 | 0.333051 | 1.443694 | 0.320344 | 0.170579 | 0.216149 | 0.0637552 | 0.309657 | 0.13585 | 0.110838 | 4.944857 | 0.118487 | 0.3548 | 0.0689406 | 0.20007 | 0.07144 | 0.44224 | 0.06239 | 0.60192 | 2.3196 | 3.51659 | 4.73393 | 1.95574 | | 23.00000 |
| S3 | 1 | 2 | 3 | 10 | 11 | 12 | 13 | 14 | 15 | 6 | 7 | 8 | 9 | | | | | | | | | | | | |
| | 2.04225 | 1.34668 | 5.83755 | 4.36892 | 0.99748 | 19.99442 | 3.29033 | 2.04046 | 2.43386 | 9.37927 | 14.21926 | 19.14154 | 7.90798 | | | | | | | | | | | | 93.00000 |
| | 0.285476 | 0.188246 | 0.816001 | 0.610709 | 0.139432 | 2.794919 | 0.4599385 | 0.285225 | 0.340218 | 1.31108 | 1.987639 | 2.675699 | 1.10542 | | | | | | | | | | | | 13.00000 |
| S4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | | | | | | | |
| | 2.04225 | 1.34668 | 5.83755 | 25.36082 | 7.76465 | 9.37927 | 14.21926 | 19.14154 | 7.90798 | | | | | | | | | | | | | | | | 93.00000 |
| | 0.197637 | 0.130324 | 0.564924 | 2.454273 | 0.751418 | 0.907671 | 1.3760578 | 1.852407 | 0.765289 | | | | | | | | | | | | | | | | 9.00000 |

## 1997

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S2 | 1 | 2 | 3 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 12 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 15 | 6 | 7 | 8 | 9 | Sum |
| | 2.52553 | 1.48649 | 5.90717 | 1.94262 | 1.73825 | 1.03419 | 0.29211 | 1.53709 | 0.89742 | 0.79428 | 26.15384 | 0.59031 | 1.73012 | 0.21673 | 1.05437 | 1.21125 | 2.54556 | 0.77482 | 2.91050 | 13.86249 | 21.48717 | 29.98440 | 10.32330 | 131.00000 |
| | 0.443413 | 0.260987 | 1.037136 | 0.341070 | 0.305188 | 0.181575 | 0.051286 | 0.269870 | 0.157563 | 0.139453 | 4.591896 | 0.103642 | 0.303762 | 0.038052 | 0.185119 | 0.212663 | 0.446931 | 0.136037 | 0.511004 | 2.433872 | 3.772556 | 5.264437 | 1.812488 | 23.00000 |
| S3 | 1 | 2 | 3 | 10 | 11 | 12 | 13 | 14 | 15 | 6 | 7 | 8 | 9 | | | | | | | | | | | |
| | 2.52553 | 1.48649 | 5.90717 | 6.54424 | 1.69170 | 26.15384 | 4.80278 | 3.32038 | 2.91050 | 13.86249 | 21.48717 | 29.98440 | 10.32330 | | | | | | | | | | | 131.00000 |
| | 0.25062 | 0.14751 | 0.58621 | 0.64943 | 0.16788 | 2.59542 | 0.47661 | 0.32950 | 0.28883 | 1.37567 | 2.13231 | 2.97555 | 1.02445 | | | | | | | | | | | 13.00000 |
| S4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | | | | | | |
| | 2.52553 | 1.48649 | 5.90717 | 34.38979 | 11.03367 | 13.86249 | 21.48717 | 29.98440 | 10.32330 | | | | | | | | | | | | | | | 131.00000 |
| | 0.173509 | 0.102125 | 0.405836 | 2.362657 | 0.758038 | 0.952385 | 1.476218 | 2.059997 | 0.709234 | | | | | | | | | | | | | | | 9.00000 |

## *Appendix E. Graphs of Spearman Correlations (1947 - 1997)*

## Table of Contents

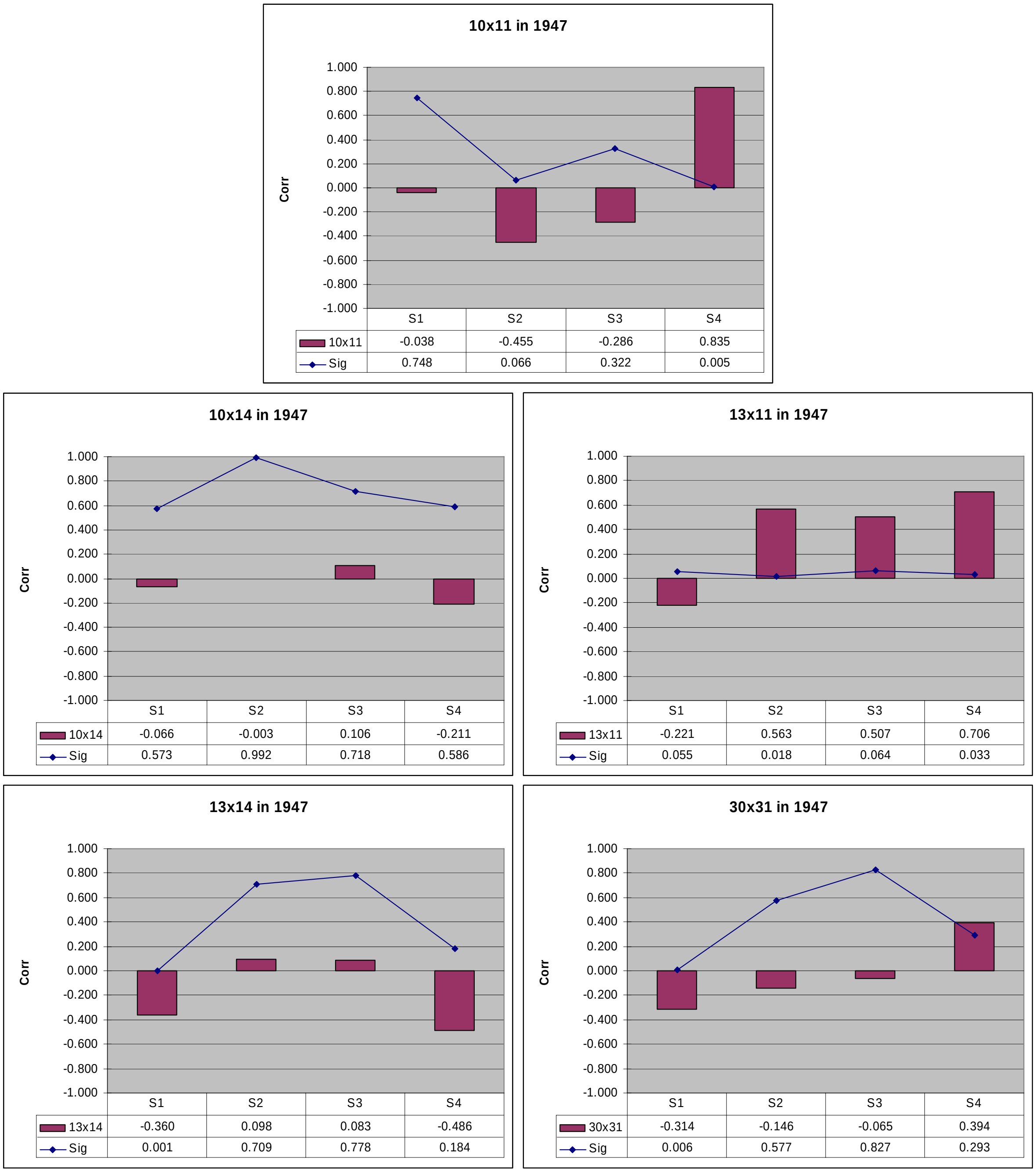



Figure 1. Spearman Correlations in 1947

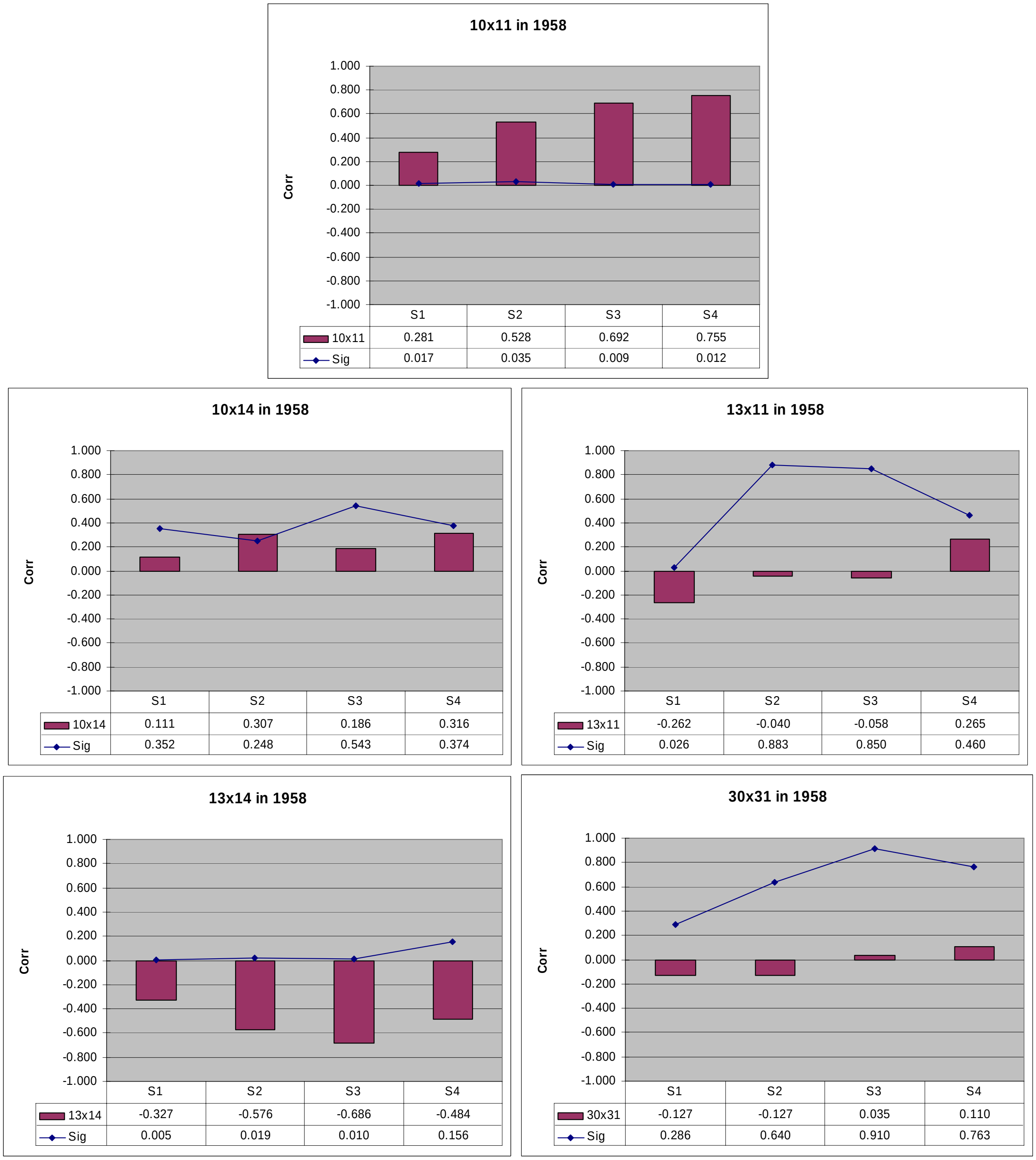



Figure 2. Spearman Correlations in 1958

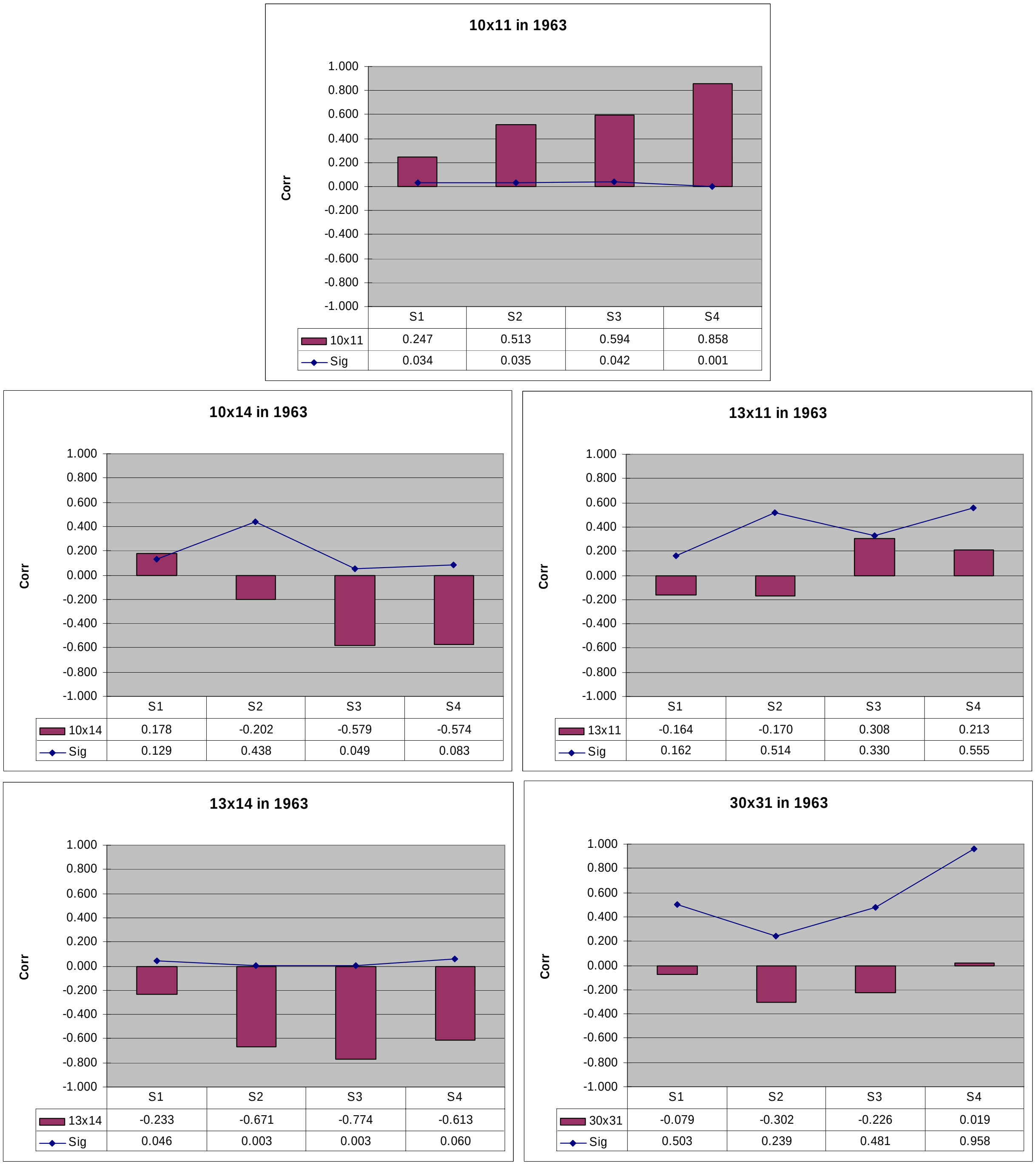



Figure 3. Spearman Correlations in 1963

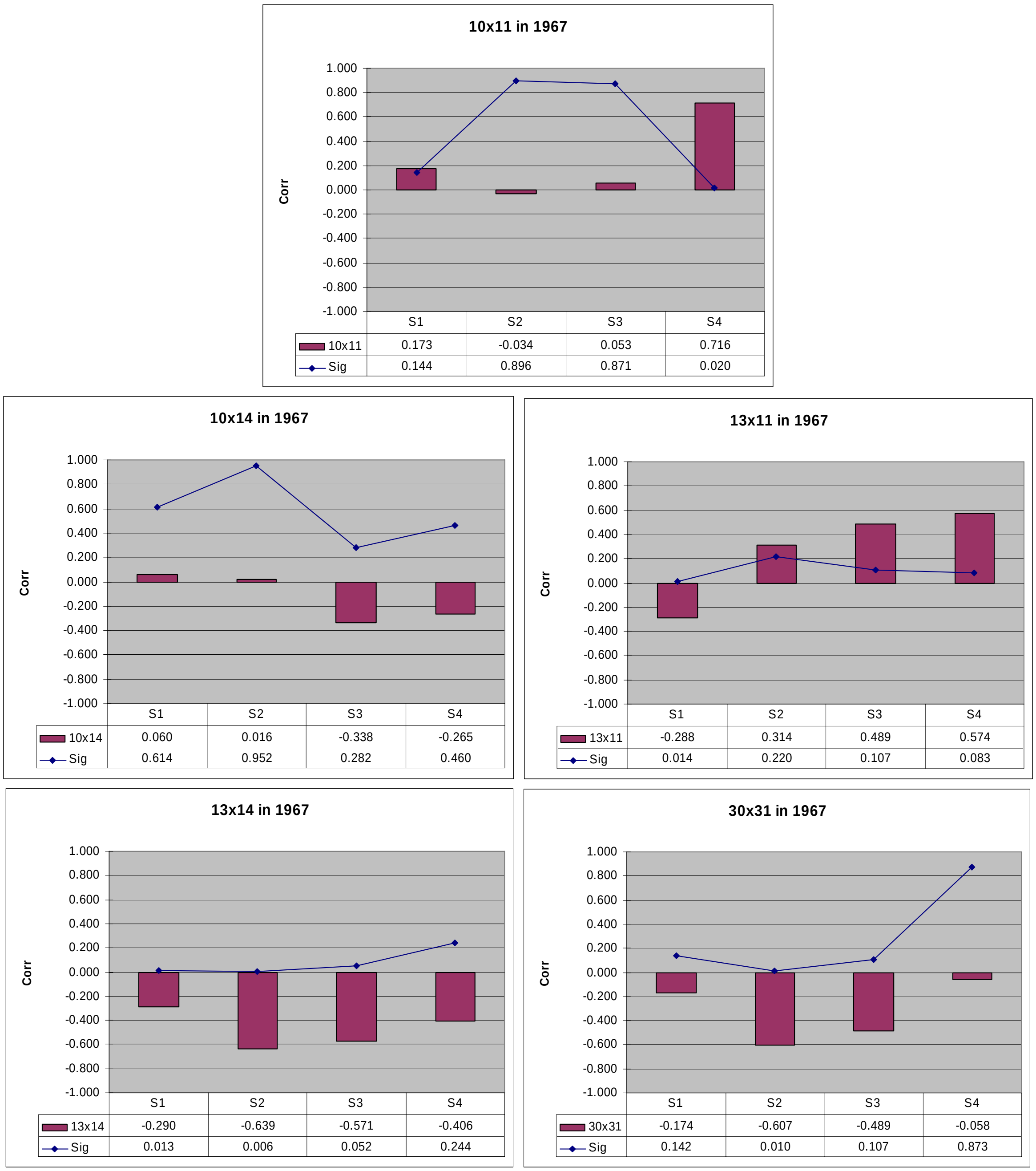



Figure 4. Spearman Correlations in 1967

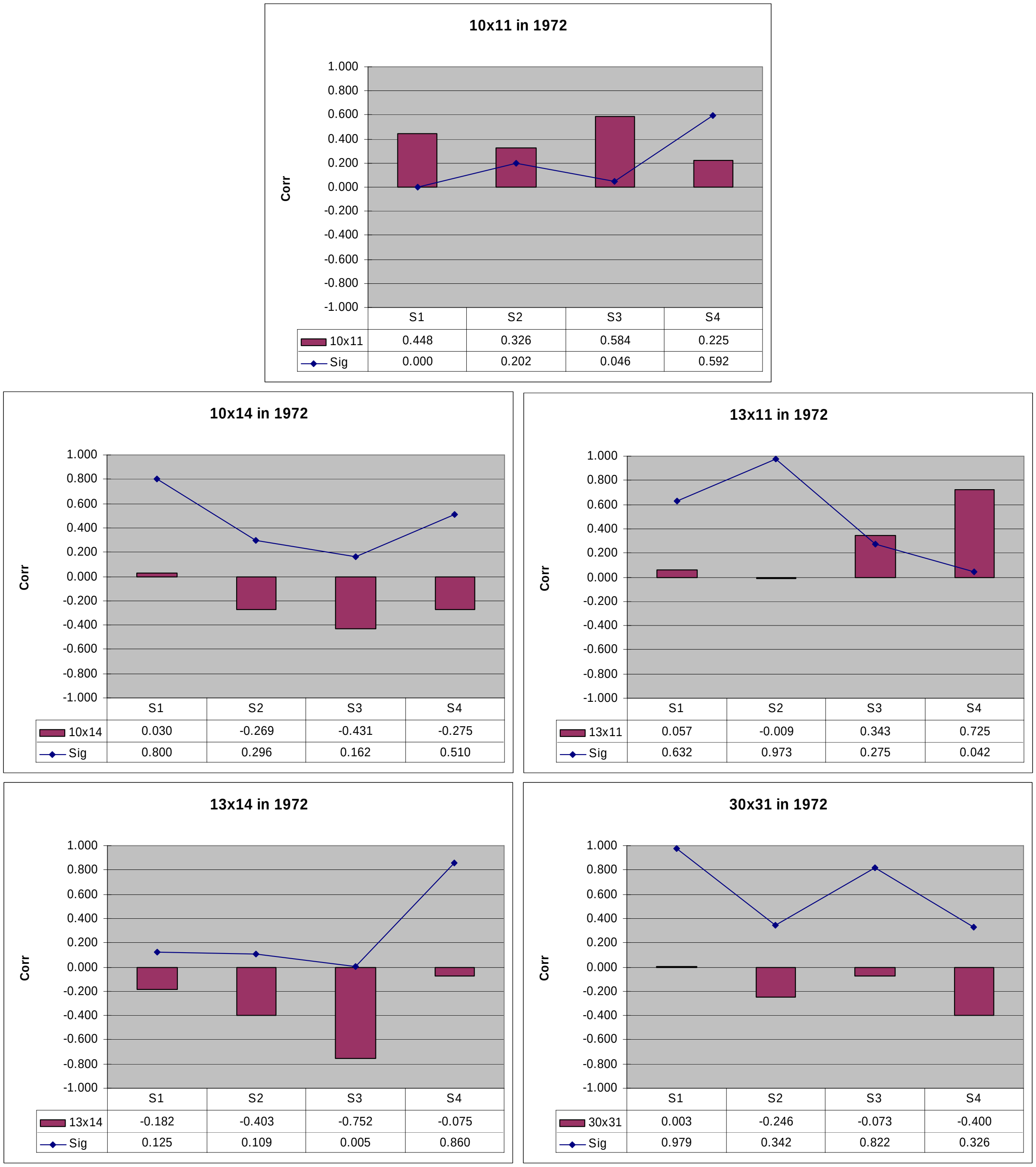
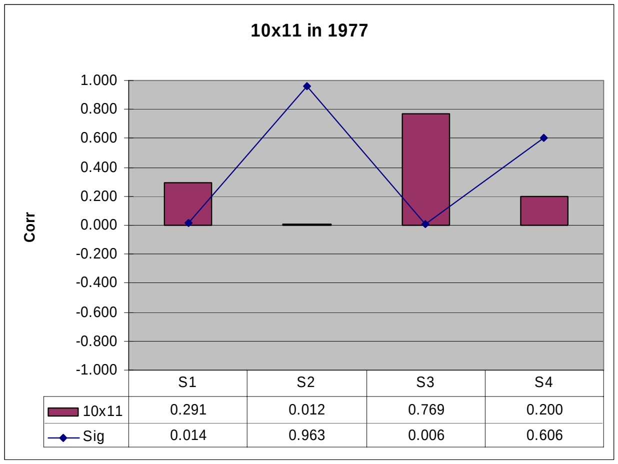
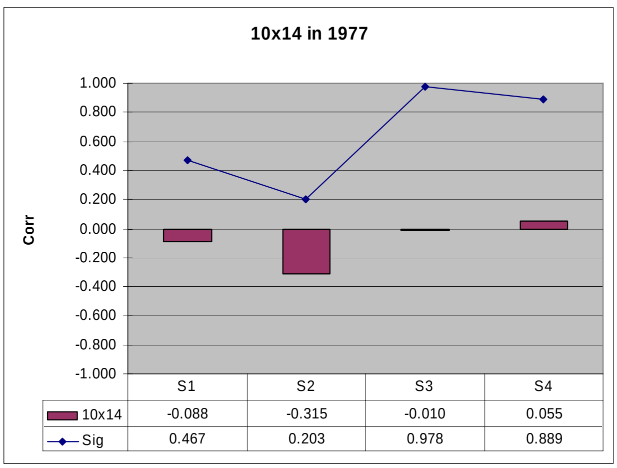


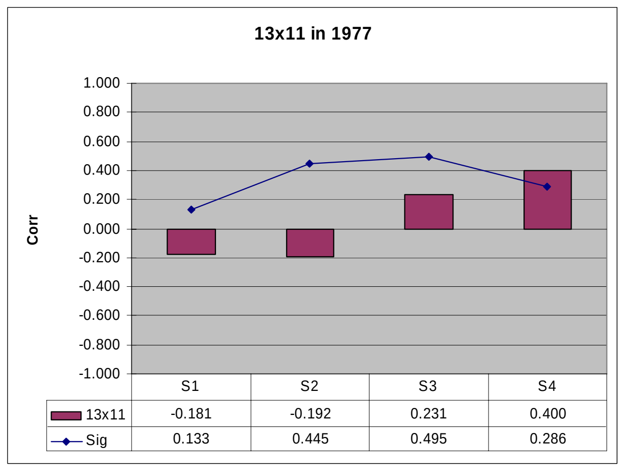

Figure 5. Spearman Correlations in 1972



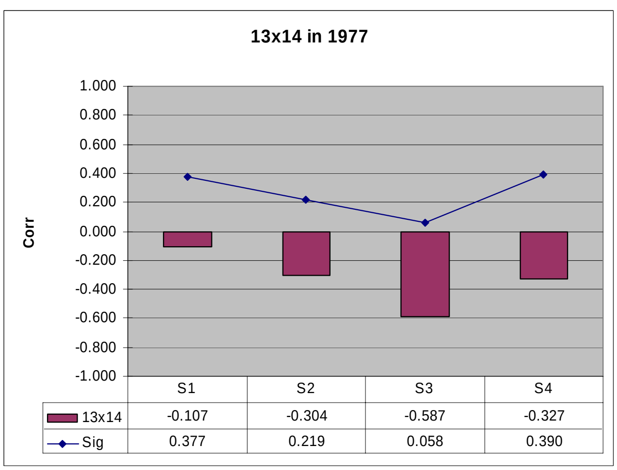

| | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| 10x11 | 0.291 | 0.012 | 0.769 | 0.200 |
| Sig | 0.014 | 0.963 | 0.006 | 0.606 |



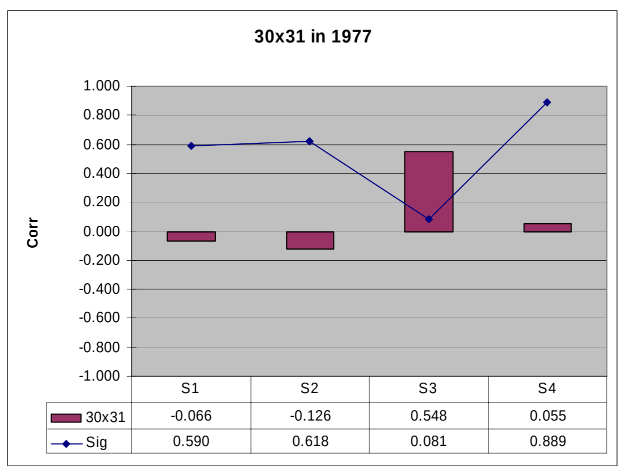

| | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| 10x14 | -0.088 | -0.315 | -0.010 | 0.055 |
| Sig | 0.467 | 0.203 | 0.978 | 0.889 |




| | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| 13x11 | -0.181 | -0.192 | 0.231 | 0.400 |
| Sig | 0.133 | 0.445 | 0.495 | 0.286 |




| | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| 13x14 | -0.107 | -0.304 | -0.587 | -0.327 |
| Sig | 0.377 | 0.219 | 0.058 | 0.390 |




| | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| 30x31 | -0.066 | -0.126 | 0.548 | 0.055 |
| Sig | 0.590 | 0.618 | 0.081 | 0.889 |

Figure 6. Spearman Correlations in 1977

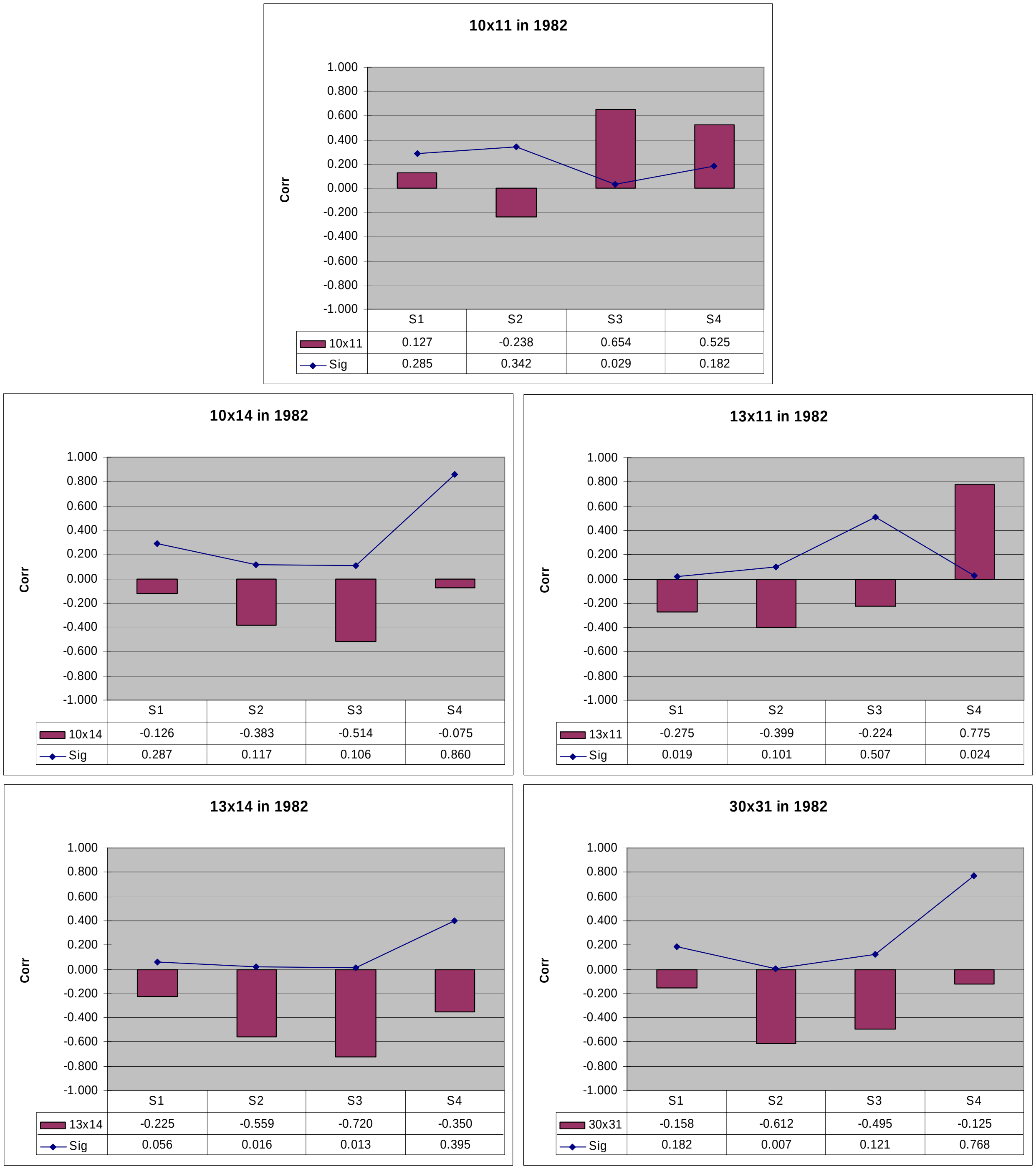



Figure 7. Spearman Correlations in 1982

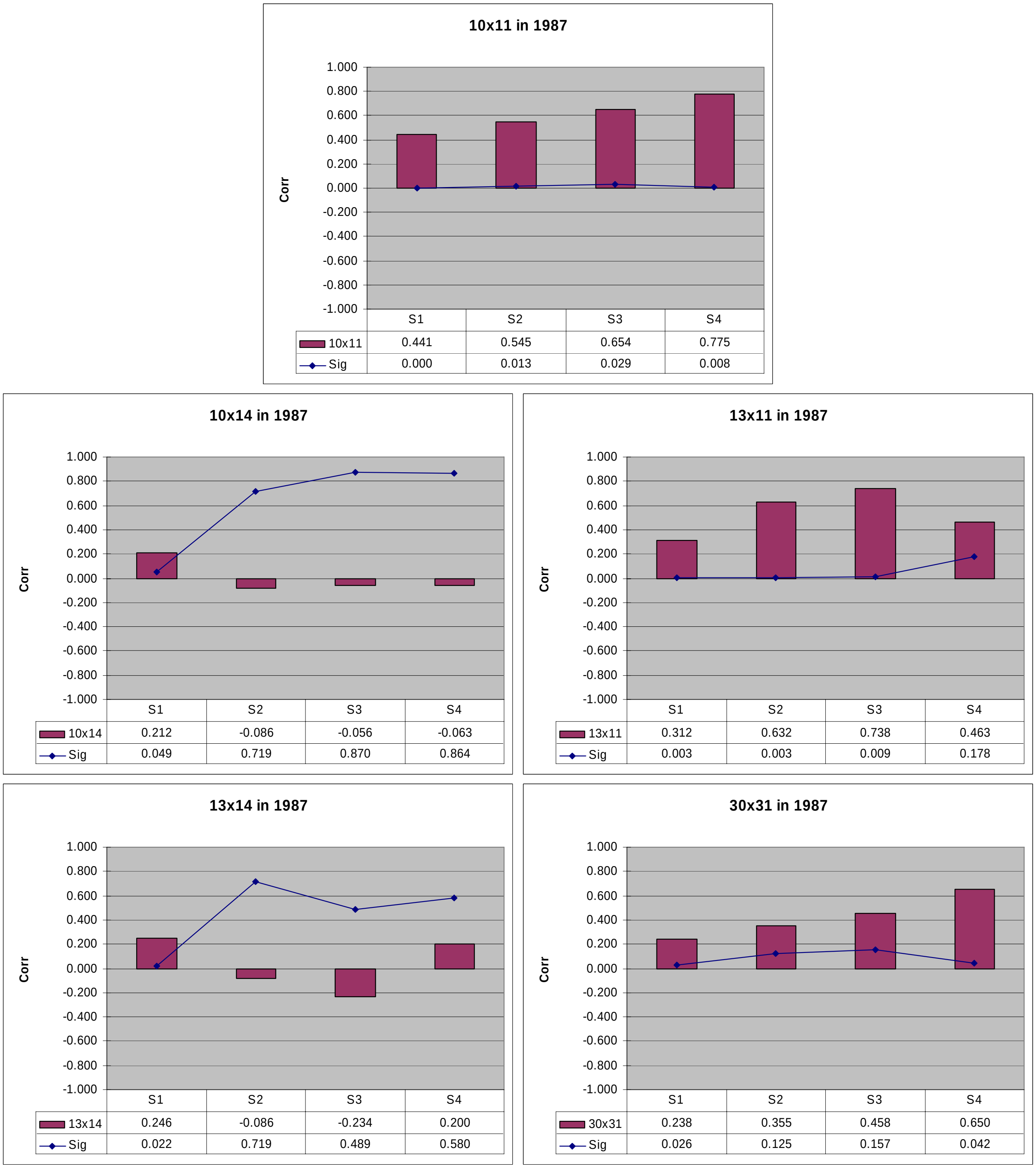



Figure 8. Spearman Correlations in 1987

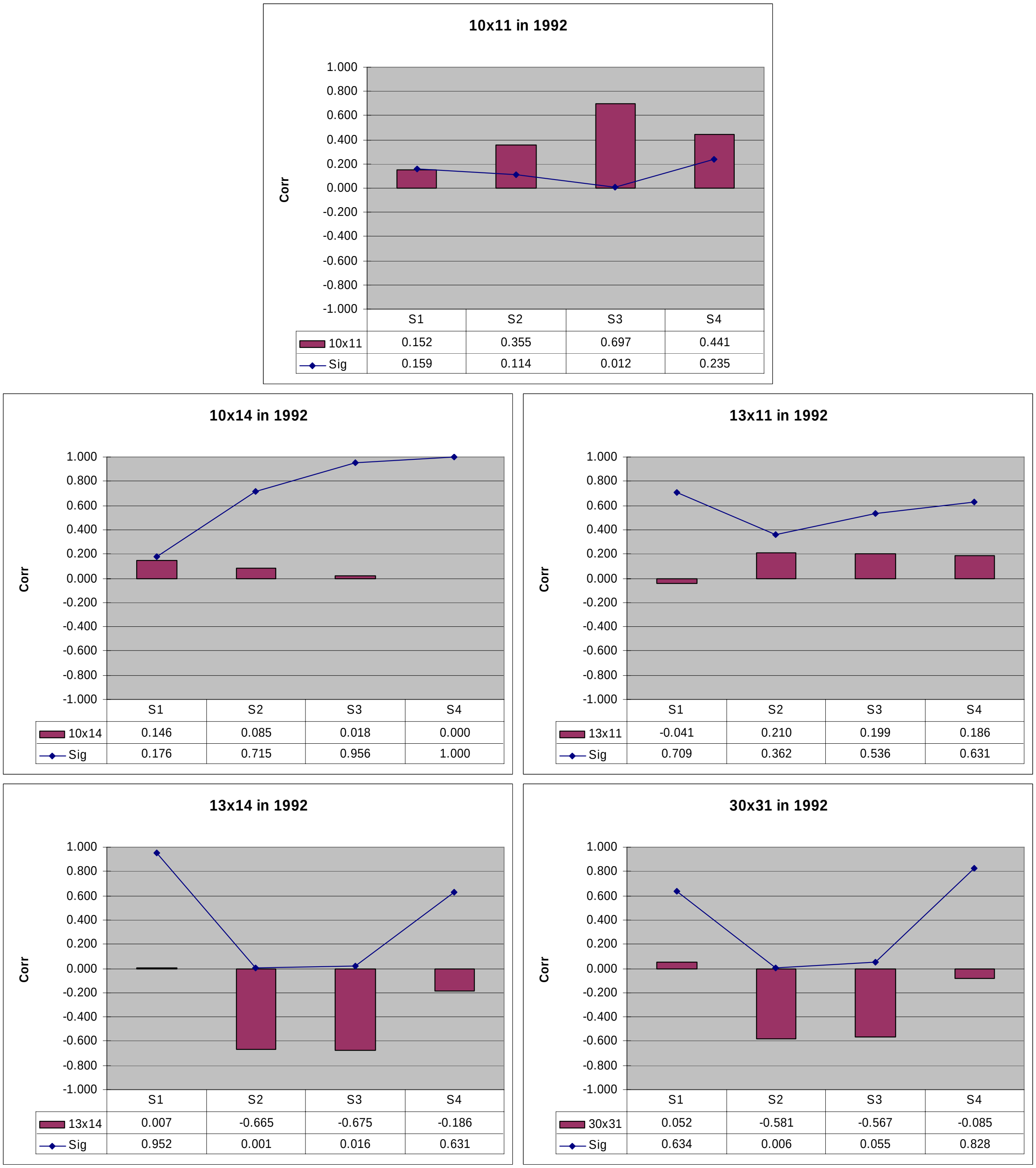



Figure 9. Spearman Correlations in 1992

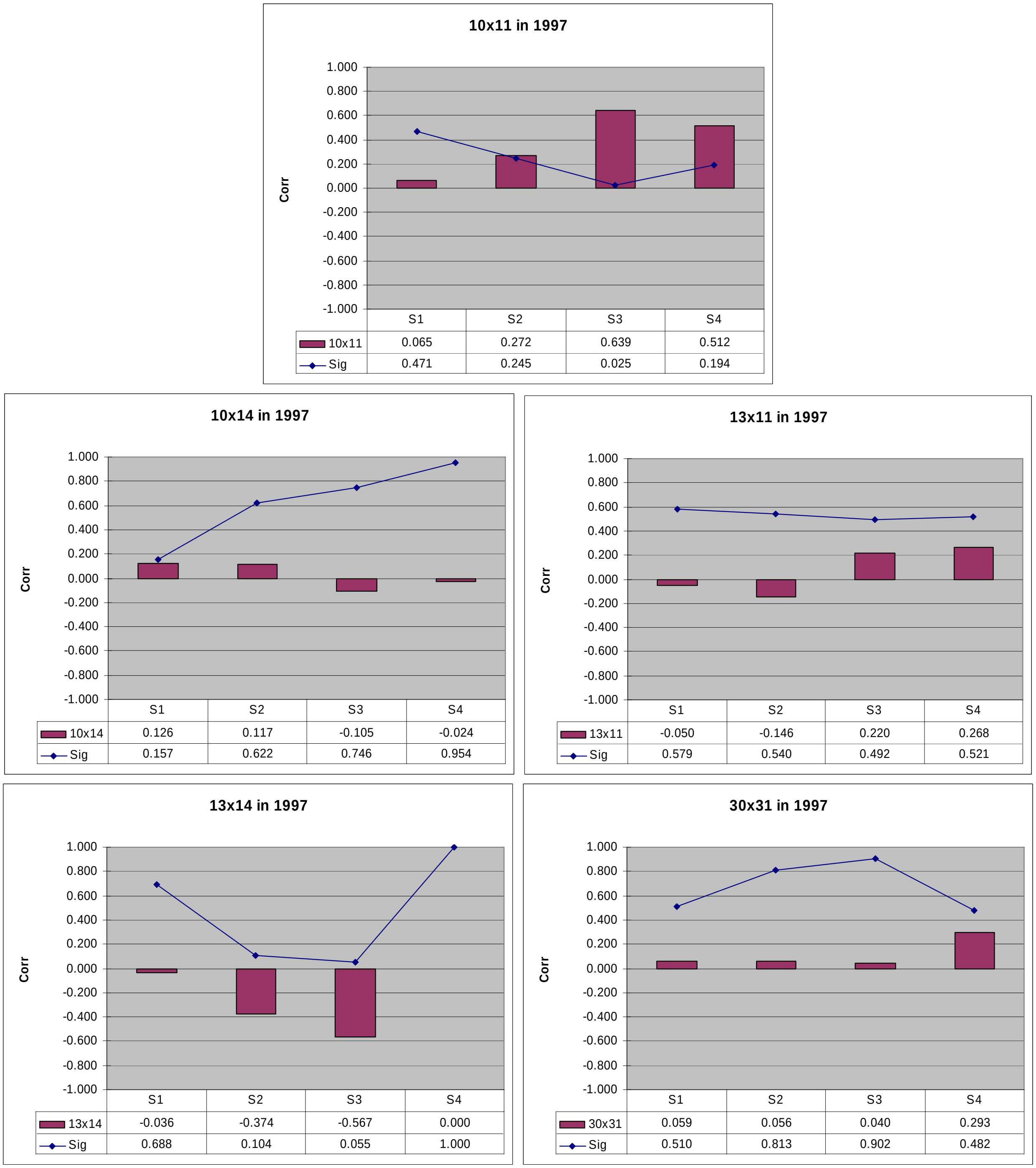



Figure 10. Spearman Correlations in 1997

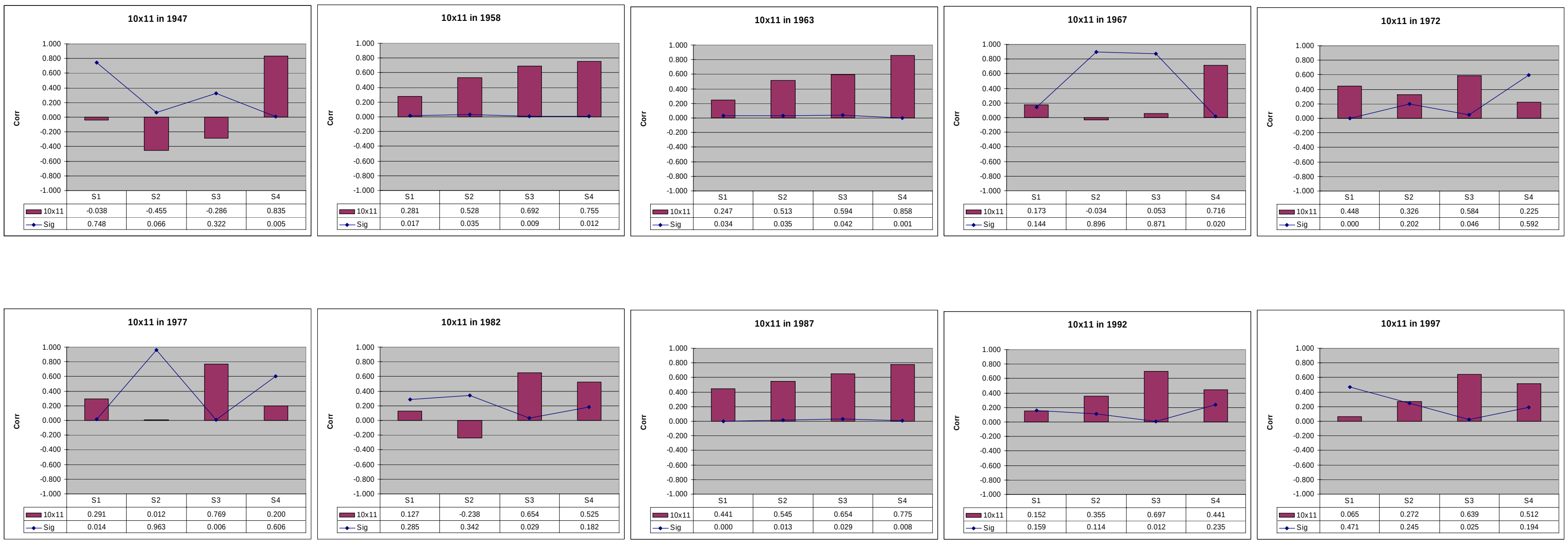



Figure 11. Spearman Correlations of 10x11 for 10 years ('47-'97)

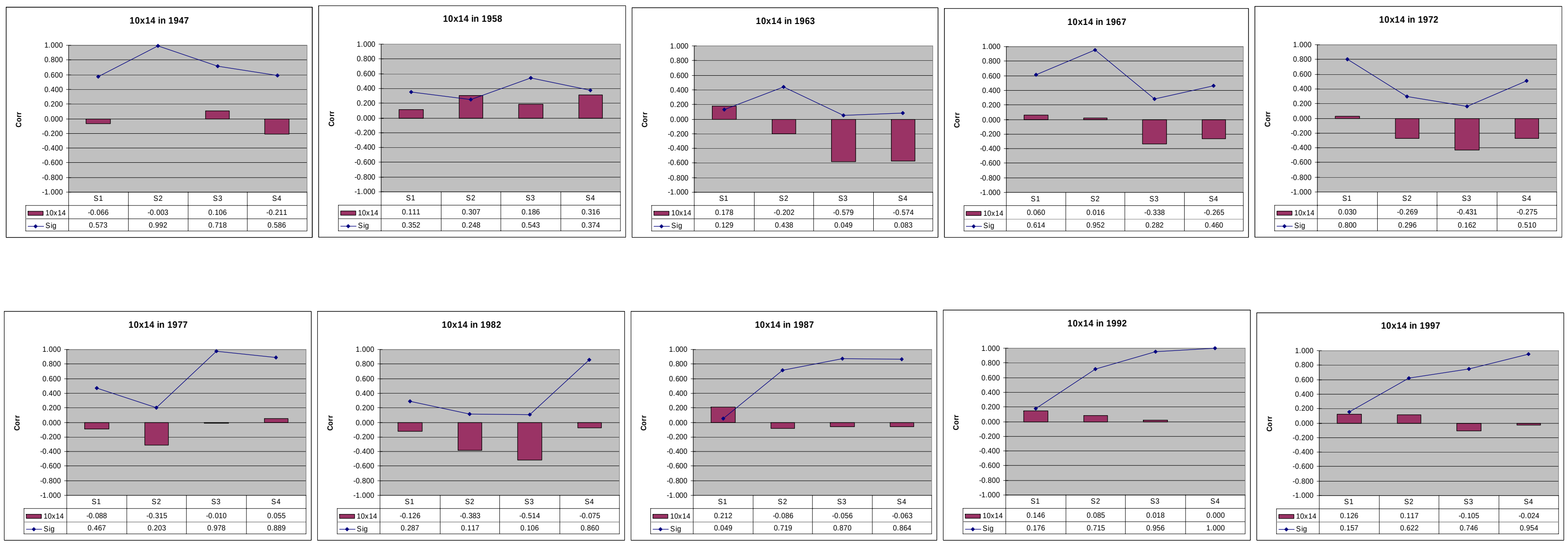



Figure 12. Spearman Correlations of 10x14 for 10 years ('47-'97)

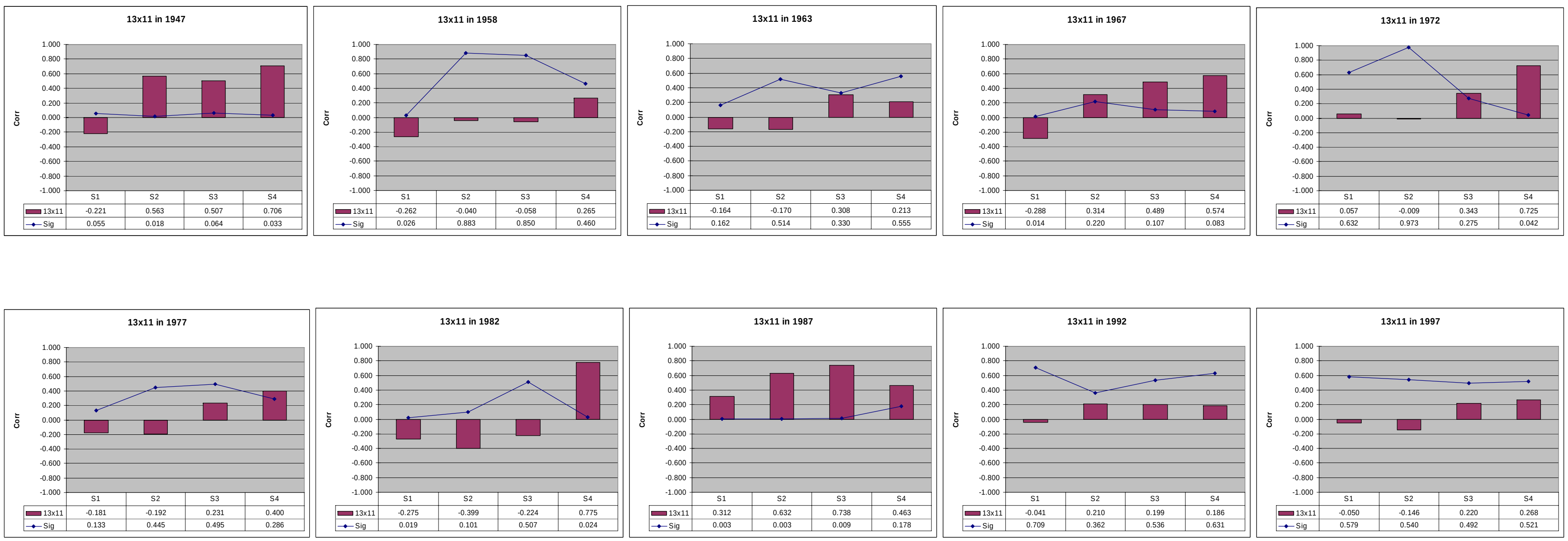



Figure 13. Spearman Correlations of 13x11 for 10 years ('47-'97)

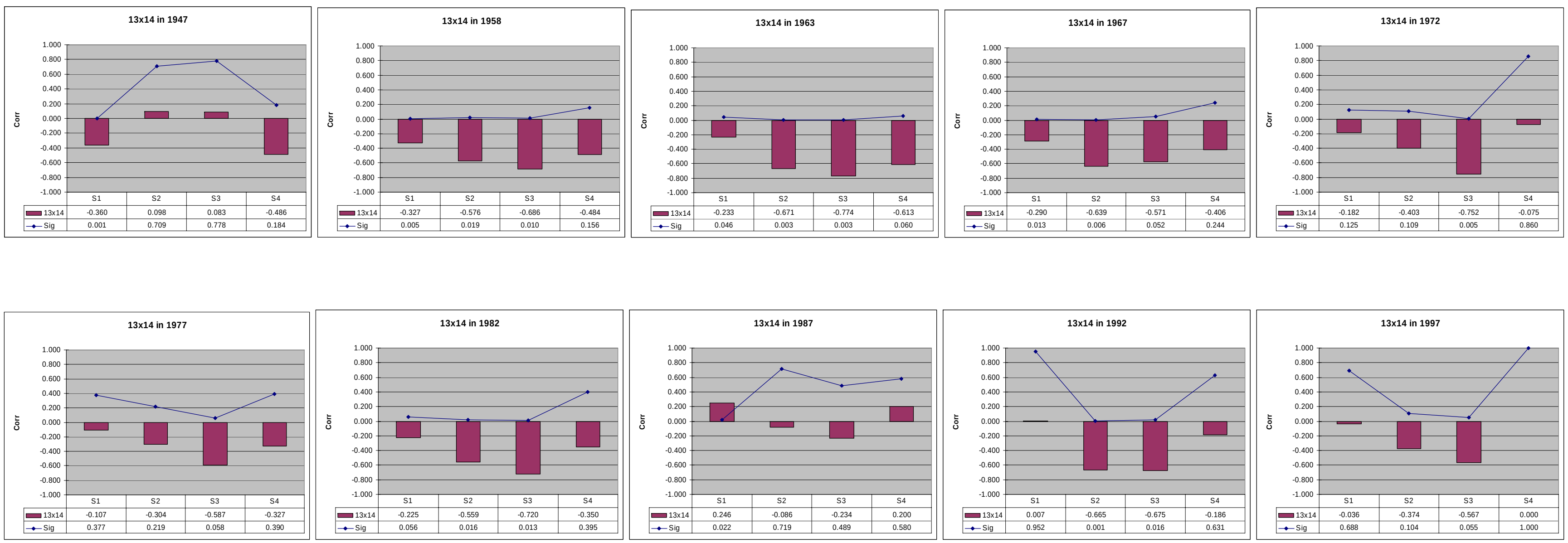



Figure 14. Spearman Correlations of 13x14 for 10 years ('47-'97)

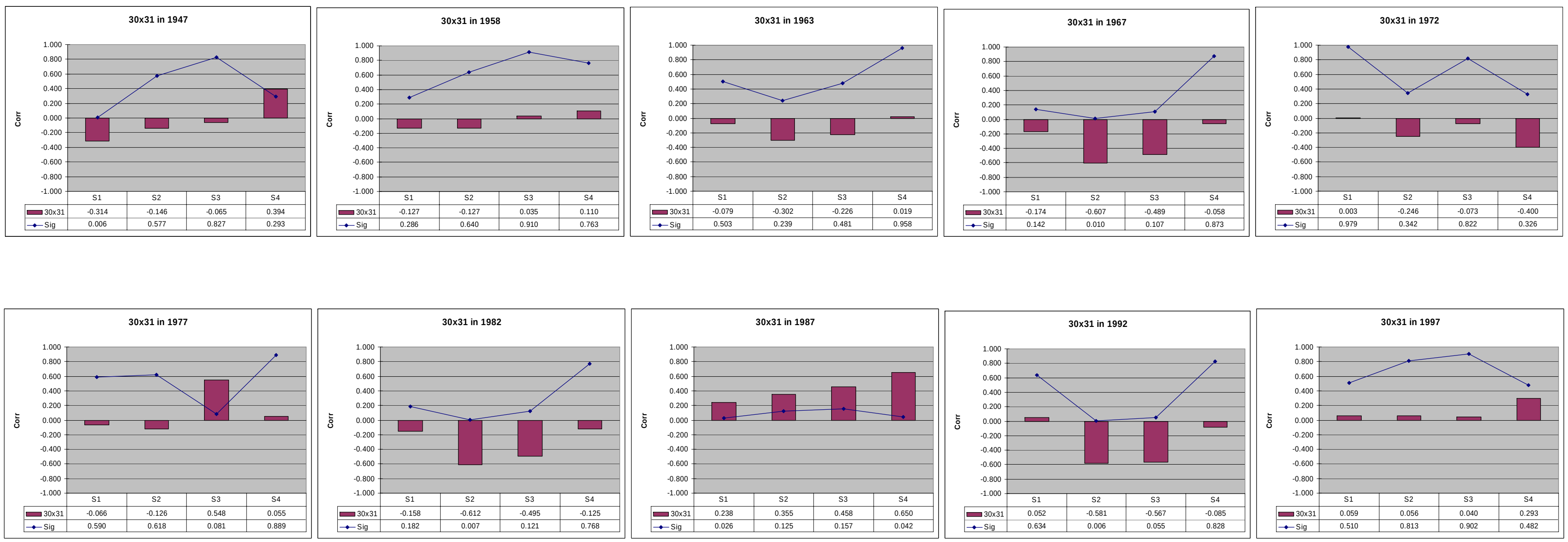



Figure 15. Spearman Correlations of 30x31 for 10 years ('47-'97)