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Technology induced economic growth in the United States: Empirical testing using spatial-temporal estimation procedures

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DRAFT I

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Public Infrastructure and Private Capital: Examination of the Technology Sector in the Washington DC Metropolitan Region

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ABSTRACT

In this paper, we examine the role of infrastructure in the growth of the technology sector in the Washington DC metropolitan region. The motivation is based on the complementary relationship between infrastructure and private capital that is found in resource based sectors of the economy. As the US economy is moving from a resource based to a technology intensive one, it is pertinent to extend the analysis to the technology intensive sectors of the economy. We also introduce the application of a new methodology -- the Getis-Ord spatial screening filter to examine the effect of spatial auto- correlation in regression analysis. Policy implications and extensions for future research are also discussed.

Public Infrastructure and Private Capital: Examination of the Technology Sector in the Washington DC Metropolitan Region

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I. Introduction

Public investments have widely been used to stimulate economic growth and attract private investment. Specifically, public infrastructure investments have been used to facilitate industrial location and enhance the productivity of private factors of production. While there is a large literature on the complementarity between public and private capital, the extension of this work to the rapidly growing technology sectors has been limited. The examination of factors influencing the growth of technology sectors is critical in understanding the economic development process as institutions and organizations across the U.S. and throughout the world are under great adapting to the impact of new technologies. These technologies are increasingly becoming standard components of most production and service delivery systems (up and down the value delivery chain), including manufacturing, design, finance, marketing, sales, and distribution.

The availability and quality of reliable public infrastructure¹ influences economic productivity and social welfare in at least two basic ways. First, infrastructure as an intermediate public good takes part directly or indirectly in production processes. Second, the availability of infrastructure offers implicit incentives to individuals and firms when they consider establishing their residence or locating a business or industry. There is a growing body of literature suggesting that public investment in infrastructure and private investment are complementary, but is dependent on the existing network density (Hulten and Schwab, 1993), as well as on the geographical and sectoral level of analysis (Lynde and Richmond,

¹ Physical infrastructure includes roads, streets, bridges, telecommunications, power, water treatment and distribution systems, irrigation, waterways, airports and mass transit.

1993; Nadiri and Mamuneas, 1996 a & b). Specifically, the role of infrastructure in industrial productivity is more closely linked to some sectors than aggregate industry wide estimates would suggest . However, the effects of these investments on output, incomes, and private capital formation depend on level of regional development, initial endowments, and inter-jurisdictional spillovers, among other factors. It is important to be sensitive to temporal and spatial effects of these investments during policy making as well as estimating the relationships among these factors.

In the United States, road linkages emerge as an important factor influencing the location decision of private manufacturing industries. For example, using a conditional logit model with Dunn and Bradstreet location decision data for 1607 manufacturing plants, Bartik (1985) estimated that roads infrastructure has a positive and significant effect on attracting new business. Similar results have been found in other industrialized countries. Seitz and Licht (1992) examined the relationship between infrastructure and private capital for 11 federal states in (West) Germany between 1970 and 1988 using a trans-log cost function. They found that public capital (infrastructure) formation encouraged private investment and also empirically demonstrated that a distinction between investment in structures vs. equipment is of critical importance in the context of private capital because the effects of the former are of far greater importance than the effects of the latter. Similarly, in Scotland, Button, Leitham, McQuaid, and Nelson (1995) found that road linkages were most highly rated factor influencing the location decision of new firms in the industrial / business park zoned land of the Strathclyde region.

The literature on infrastructure and regional economic growth indicates varying degrees of complementarity between public infrastructure and private capital and employment formation². Most existing studies highlight the importance of transport infrastructure in this development process. In this paper, we examine the linkages between public infrastructure and the growth of the technology sector in the Washington DC metropolitan region. Specifically, we examine the role of infrastructure vis-a-vis other development factors in the growth of the technology sector. Indicators of transport and educational attainment are used as

² Stough, Lall, and Trice (1998) provide a recent survey of the relationship between public and private investment .

infrastructure variables to incorporate the concept of physical and human capital. The research work presented in this paper extends the analysis of the public-private investment relationship to the technology sector of the economy. We also introduce the Getis-Ord spatial screening methodology in measuring the determinants of technology led economic development. The findings presented in this paper are important for public investment allocation decisions to stimulate technical progress in the regional economy.

Following this introduction, Part II presents the definition of the technology sector and description of the data used in the analysis. Recent trends in the distribution of the technology sector in the counties and cities of the Washington DC metropolitan region are also provided in this section. Part III provides the methodology, model specification and results from the empirical analysis. Part IV provides regional policy implications and suggestions for future research.

II. Data and Definitions

In this study, the technology sector is considered as the engine of economic growth, and regional technology intensity is considered as an indicator of regional propulsion. Thus, it is critical to examine the factors determining the growth of the technology sector. The thesis of technology led economic growth is consistent with the works of Armington (1986), Erickson (1994), Markusen et al., (1986), Malecki (1983), Schumpeter (1942), and Stough et al. (1997 a&b), among others.

It is important to define what is meant when referring to the technology (or technology intensive) sectors of the economy. There are many different definitions of technology sectors and 'high-tech' employment (Armington, 1986; Markusen, 1987; Stough, 1996; Luker and Lyons 1996). The definition of technology sectors used in this paper is based on the Armington (1986) index, subsequently modified by Stough et al. (1996) to incorporate information and service based activities. The empirical analysis in this paper uses data on technology intensive **employment and establishments** in the Washington DC Metropolitan

Region from 1988 through 1995³. This is first time that such an extensive data set using technology sector definitions at the four digit SIC level has been used for this kind of analysis. Armington (1986) defined high technology employment as a subset of the U.S. Standard Industrial Classification (SIC) codes. The SIC system of codes classifies all economic activity in the U.S. into twelve divisions, A through K, by primary industry. Within each division, two-digit SIC codes describe major groups. Within major groups, three-digit SIC codes describe industry groups, and four-digit codes describe specific industrial activities. At the four-digit level, there are approximately fifteen hundred SIC codes.

The Armington (1986) index of high technology SIC codes was updated by Stough et al. (1997) to adjust for changes made in the SIC definitions in 1987, and to include the growing high technology service sector. Armington's index identifies sectors that have more than average amount of investment in R & D and more than average proportions of engineering employment (and other related scientific employment). The augmented and adjusted index (Stough, et. al., 1997) contains 130 SIC codes at the four-digit level (see Appendix 1). The sectors defined by these 130 SIC codes are defined as technology intensive sectors (often referred to as 'technology sectors' in the remainder of the text). We used the updated (Stough, et. al., 1997) definition of the technology sectors in this analysis.

The period 1988-1995 was selected for several reasons. First, the most recent data available at the time of this study were for 1995. Second, 1988 was the crest of a business cycle after which growth slowed and fell into recession in 1990-1991. While growth picked up marginally in 1991 and 1992 it did not exhibit strong growth until the 1993-1994 period. The analysis is conducted for a period which is end-anchored with years that experienced strong growth and which surround a recession, and therefore reduce the bias that can result if 'peak to valley' or 'valley to peak' anchors are used. The growth trends in this period

³ Data in electronic format (CD-ROM) on business and employment patterns for every county in the U.S. were available from the U.S. Department of Commerce, through its Bureau of the Census' series entitled *County Business Patterns* for that time period. The electronic form of this data allowed it to be sorted using a relational database program, *Access*. Analysis of the data using a spreadsheet program generated regional and sectoral patterns and trends. Then, using a geographic information system (GIS), *Arcview*, maps showing these trends and patterns were produced. All analyses were for data were totally disaggregated to the county level for the Washington DC Metropolitan Region.

resembles a 'J' shaped curve with no asymptote being forecasted in the near future. Finally, the SIC Classification System was redesigned in 1987. To have used an earlier year than 1988 would have involved a major effort to reclassify industry sectors into the new post-1987 categories.

Technology Sector in the Washington D.C. MSA

The Washington MSA is a bi-state (Maryland and Virginia), and federal district (District of Columbia) region. In this MSA, the concentration of technology employment and establishments is largest in Fairfax County, VA with nearly 87,000 technical jobs with other notable concentrations in Montgomery County, MD. Further, other close in jurisdictions (District of Columbia, Prince Georges County, MD and Arlington County, VA) have between 20,000 and 40,000 technical employees. In short, technical employment is concentrated in Fairfax County, VA and other relatively central parts of the region.

The large Washington region may be viewed as having a major anchor in and around Fairfax County, VA and other central jurisdictions of the Washington sub-region. One could hypothesize that technical jobs will continue to cluster around this region with the largest growth occurring around the anchor, much as shopping centers develop (i.e., around anchors of a mall or a development district).

III. Methodology, Model Specification and Empirical Analysis

The focus of this paper is to examine the role of infrastructure in influencing the growth of the technology sector in the Washington DC Metropolitan Region. An OLS model was constructed to explain the technology based structural composition of the regional economy with technology establishments as a percentage of total establishments. Establishments are used as a proxy for industry demand and the flow of capital in the region. Per Capita Highway Expenditures, Per Capita Income, Highway Density and the percentage of the adult population with a College Degree are used as explanatory variables for the two years used in the analysis (1988 and 1995).

Determining Spatial Interaction

One of the problems facing spatial data in a regression framework is of spatial autocorrelation. In its most general interpretation, spatial autocorrelation is concerned with the degree to which objects or activities at some place (in space) are similar to other objects or activities located nearby. The existence of spatial autocorrelation is reflected in Tobler's (1970) first law of geography which suggests that "everything is related to everything else but near things are more related than distant things." Spatial autocorrelation can be interpreted as a descriptive index, measuring aspects of the way things are distributed in space. However, at the same time it can be seen as a causal process, measuring the degree of influence exerted by something over its neighbors. It is the later connotation that is of greatest interest to our research. In this paper, we will identify spatial clustering of technology activities by determining the presence of spatial autocorrelation. Ordinary least squares (OLS) estimates are biased and inconsistent in the presence of spatial autocorrelation. The spatial aspects underpinning many social phenomena, especially the functional form of the relationships, invariably influence the results obtained in multivariate regression approaches.

To identify the extent of spatial autocorrelation, Moran's I was calculated for each of the independent variables as an indicator of spatial interaction. The Moran's I is an indicator of spatial correlation across the system as a whole. Table 1 shows that Per Capita Income, Highway Density and Share of Technology all experience some level of spatial autocorrelation aggregated across the region. As the focus of the research is not on identification of spatial autocorrelation but rather the treatment of this problem, a description of these statistics is not provided here. This test provides the basis to expand the analysis and justifies using the Getis-Ord methodology to filter out the spatial component.

Getis (1990) presents a technique of analysis to estimate parameters of spatially stochastic independent variables. Furthermore, Getis outlines an approach to screen for spatial dependence in regression analyses. This approach has direct relevance to research in proximity centered analyses. The Getis approach attempts to remove the spatial association in variables within a regression equation to obtain a "spaceless" association among variables,

one with little or no spatial dependence. The link with proximity in this approach pertains to the distance in which the degree of spatial dependence (or residual spatial variation) is greatest. Once this distance is established, data for both independent and dependent variables can be screened so that any spatial association is removed from the regression equation. This procedure allows the researcher to examine the effects of the spatial configuration of the data on regression results and then properly re-estimate the results.

Formal Treatment of Spatial Clustering

If spatial autocorrelation is found among the dependent and the independent variables, we plan to use the Getis -Ord (1992) methodology to filter out the spatial component of the regression.

$$G_i(d) = \frac{\sum_{j=1}^n w_{ij}(d)x_j}{\sum_{j=1}^n x_j}, j \neq i$$

Where w_{ij} is a 1/0 spatial weight matrix (1 when within distance d of a given i and 0 otherwise)

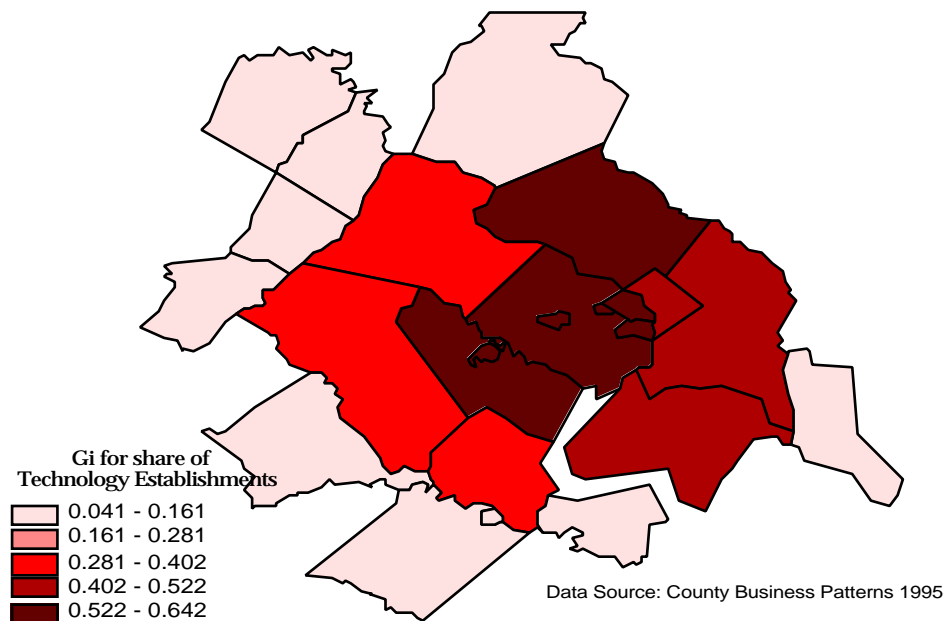
$$x_i^* = \frac{x_i \frac{W_i}{n-1}}{G_i(d)}$$

Where $W_i/n-1$ is the mean (random expectation) - when solved for all x_i , then X^* represents the filtered variable and the difference b/w $X-X^*$ is a new variable L

The first equation specified above is used to calculate the Getis statistic that identifies the distance at which the degree of spatial dependence is maximum. The weights matrix w_{ij} is a binary spatial weights matrix (1 when within distance d of a given i and 0 otherwise), and x_j at distance (d) is the sum of the all neighboring units for the specified variable at a specified distance from the centroid of unit i . The value of $G_i(d)$ for each i is maximum where the ratio of the distance weighted neighbors effect to the sum of all attributes for that variable (excluding county i) is the greatest. For example, if a county 1 has counties 2 and 3 as first contiguity neighbors, and 4 and 5 as second contiguity neighbors, then the value of the denominator will be $(2,3,4,5)$ for each variable. This study attempted to examine distance

based contiguity bands ranging 27.0 miles in radius. This was the distance from the centroid of county i to the centroid of its farthest neighbor county j .

Figure 1



This approach attempts to remove spatial association in the variables within a regression equation to obtain a "spaceless" association among variables. Once the distance at which spatial dependence is maximum has been established, data for both independent and dependent variables can be screened so that any spatial association is removed from the regression equation. The second equation illustrated above can be used to examine this issue. In this equation, $W_i/(n-1)$ is the mean (random expectation) - when solved for all x_i , then X_i^* represents the filtered variable and the difference between $X-X^*$ is a new variable L .

Figure 2

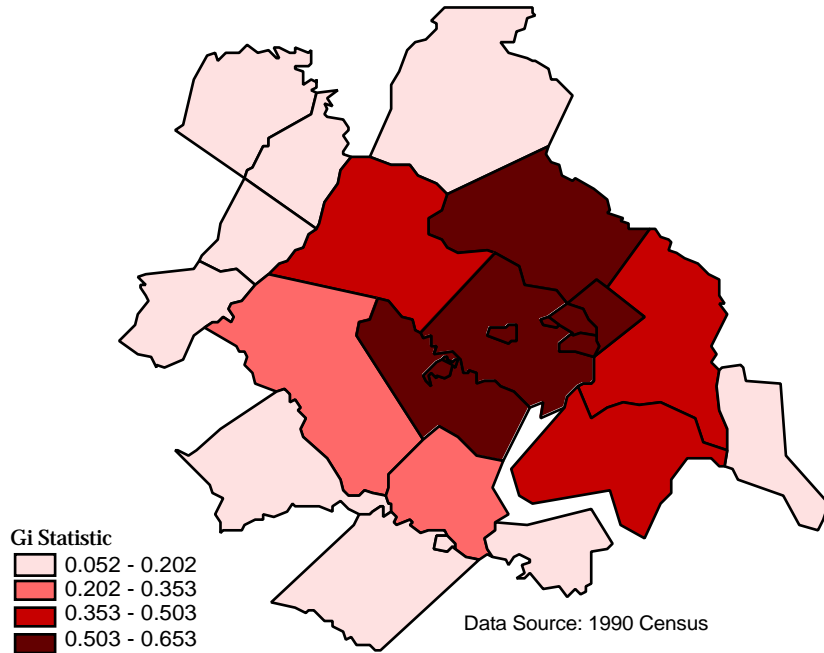


Figure 1 shows the Getis statistic (G_i) for each county within the region for the output variable Technology Establishments as a Percentage of Total Establishments (Technology Intensity). Unlike the Moran statistic, the Getis statistic is a local indicator of spatial association and shows the levels of each individual cluster. Fairfax County, Montgomery County and Prince William County have the highest levels of spatial interaction among all counties in the region. Figure 1 also shows that these levels of spatial association diminish the further the distance from these core counties.

The Getis method can be used to determine the spatial association for the independent variables as well. For demonstration purposes, the G statistic was calculated for the variable Percent of College Graduates. Figure 2 clearly shows that the percent of college graduates are highly clustered in the aforementioned counties.

As demonstrated above, there appears to be spatial autocorrelation at different levels of technology intensity as well as among different levels of the most significant independent variable, percent of college graduates. Now that it is known that spatial autocorrelation exists, the effect of space on technology intensity can be estimated. For this the Getis statistic is treated as one of the parameters in the OLS model. The new model is now a "spaceless" model where the effect of space is represented. Table 2 shows that estimates for both the original model and the "spaceless" model for each of the years in the study. In 1988, the effect of space accounted for 14 percent of the variance explained. In 1995, the effect of space accounted for 7 percent of the variance explained by the original model. The effect of the independent variables is reduced in the "spaceless" model indicating that indicators such as Percent College Graduates and Per Capita Income may be highly clustered.

Table 2: Comparison of Original Model versus "Spaceless" Model

Dependent Variable Indicates Structural Composition	Share of Technology Establishments 1988	Share of Technology Establishments 1988 'Spaceless'	Share of Technology Establishments 1995	Share of Technology Establishments 1995 'Spaceless'
Per Capita Highway Expenditures	-0.021 (-1.02)	-0.032 (-1.43)	-0.002 (-0.11)	-0.037 (-1.11)
Per Capita Defense Expenditures	-0.023 (-0.86)	-0.04 (-1.55)	-0.011 (-0.42)	-0.02 (-0.66)
Per Capita Income	-0.843 (-13.60)		-0.607 (-9.49)	
Per Capita Income*		-0.86 (-5.77)		-0.72 (-5.16)
Highway Density	-0.172 (-1.46)		0.047 (0.393)	
Highway Density*		-0.31 (-1.26)		0.029 (0.093)
Percent College Graduates	1.763 (8.39)		1.09 (4.95)	
Percent College Graduates*		1.72 (4.35)		0.92 (2.22)
Adjusted R²	0.75	0.61	0.52	0.45

IV. Policy Implication and Directions for Future Research

The results from the empirical study tend to suggest that the percentage of college graduates have the most important effect on technology intensity in the Washington DC MSA. Thus human capital and investment in education infrastructure is most likely to increase the technology intensity in jurisdictions belonging to the Washington DC MSA. The findings are consistent with the nature of resources required by the technology sector. As a large part of transactions in this sector is based on information and knowledge (both in terms of production and distribution), the availability of an educated workforce is central to regional economic performance.

This situation is somewhat different than those seen historically in periods of heavy industrial activity. As the region moves from a resource based to an information based economy, traditional costs like transportation are likely to become less important. The traditional industrial structure is dominated by distributed production systems where firms minimize the unit cost of production and the transport cost to buyers and suppliers. Transport cost, other transaction costs, and institutional barriers are important inputs in the production cost structure and thus influence the location of production facilities. The foundation of the theory of optimal firm location is based on the Launhardt-Weber model (Launhardt, 1882; Weber, 1909; Isard, 1956) whose essential feature is that location parameters are sensitive to both markets and source of inputs. The main argument is that the firm's decision to locate is guided by the transportation cost of its outputs and inputs. Thus, availability of transport infrastructure was central to private industrial investment.

However, the importance of transport costs appears to have been reduced in the information era. The transfer and production of knowledge based products are becoming more important, and other transaction costs like information asymmetry, and quality of capital and labor gain increasing importance. Further, institutional barriers like regulations, barriers to entry or exit due to monopolistic or duopolistic market structure, and common set of laws are important in location characteristics of firms. Thus, the availability of skilled and trained labor becomes very important in the technology sector, primarily to produce knowledge intensive products, but also to address the growing costs of information asymmetry and imperfect market structures. The empirical estimates also have shown that the percent of college graduates are positively related to regional technology intensity and physical infrastructure variables like highway expenditures and highway density are not statistically significant in influencing regional technical intensity.

An interesting extension to this research would be the inclusion of variables that represent telecommunication infrastructure. We hypothesize that telecom network infrastructure will have a positive effect on technology activities due to its substitution effect on traditional transport networks. Telecommunication networks perform similar functions for

the technology sector as traditional transport networks did for the resource intensive sectors -- both serve as means for providing access to the region and/or opening the region to facilitate trade and commerce.

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APPENDIX 1

LIST OF SICs USED IN THE STUDY

Advanced Manufacturing

2812	Alkalies and chlorine
2813	Industrial gases
2816	Inorganic pigments
2821	Plastics materials and resins
2822	Synthetic rubber
2823	Cellulosic manmade fibers
2824	Organic fibers, noncellulosic
2861	Gum and wood chemicals
2865	Cyclic crudes and intermediates
2891	Adhesives and sealants
2892	Explosives
2893	Printing ink
2895	Carbon black
2899	Chemical preparations, n.e.c.
3264	Porcelain electrical supplies
3364	Nonferrous die-casting except aluminum
3482	Small arms ammunition
3483	Ammunition, exc. for small arms, n.e.c.
3484	Small arms
3489	Ordnance and accessories, n.e.c.
3492	Fluid power valves and hose fittings
3531	Construction machinery
3532	Mining machinery
3533	Oil and gas field machinery
3534	Elevators and moving stairways
3535	Conveyors and conveying equipment
3536	Hoists, cranes, and monorails
3537	Industrial trucks and tractors
3543	Industrial patterns
3544	Special dies, tools, jigs and fixtures
3545	Machine tool accessories
3555	Printing trades machinery
3559	Special industry machinery, n.e.c.
3567	Industrial furnaces and ovens
3569	General industrial machinery, n.e.c.
3594	Fluid power pumps and motors
3624	Carbon and graphite products
3810	Search and navigation equipment
3821	Laboratory apparatus and furniture
3824	Fluid meters and counting devices
3825	Instruments to measure electricity
3826	Analytical instruments
3827	Optical instruments and lenses
3829	Measuring and controlling devices, n.e.c.
3860	Photographic equipment and supplies
3870	Watches, clocks, watchcases and parts

Aerospace

3721	Aircraft
3724	Aircraft engines and engine parts
3728	Aircraft parts and equipment, n.e.c.
3761	Guided missiles and space vehicles
3764	Space propulsion units and parts
3769	Space vehicle equipment, n.e.c.

Biotech/Biomedical

2833	Medicinals and botanicals
2834	Pharmaceutical preparations
2835	Diagnostic substances
2836	Biological products except diagnostic
3841	Surgical and medical instruments
3842	Surgical appliances and supplies
3843	Dental equipment and supplies
3845	Electromedical equipment
3850	Ophthalmic goods

Electronics

3612	Transformers, except electronic
3625	Relays and industrial controls
3629	Electrical industrial apparatus, n.e.c.
3651	Household audio and video equipment
3652	Prerecorded records and tapes
3670	Electronic components and accessories
3695	Magnetic and optical recording media

Environment and Energy

1310	Crude petroleum and natural gas
1320	Natural gas liquids
3561	Pumps and pumping equipment
3563	Air and gas compressors
3564	Blowers and fans
3822	Environmental controls
3823	Process control instruments
8734	Testing laboratories

Information Tech. and Telecom.

3571	Electronic computers
3572	Computer storage devices
3575	Computer terminals
3577	Computer peripheral equipment, n.e.c.
3578	Calculating and accounting equipment
3579	Office machines, n.e.c.
3661	Telephone and telegraph apparatus
3663	Radio and TV communications equipment
4810	Telephone communication
4820	Telegraph and other communications
4840	Cable and other pay TV services
4890	Communication services, n.e.c.
7371	Computer programming services
7372	Prepackaged software
7373	Computer integrated systems design
7374	Data processing and preparation
7375	Information retrieval services
7376	Computer facilities management
7377	Computer rental and leasing

7378	Computer maintenance and repair
7379	Computer related services, n.e.c.
Technology Services	
7384	Photofinishing laboratories
7389	Business services, n.e.c.
8711	Engineering services
8712	Architectural services
8713	Surveying services
8731	Commercial physical research
8732	Commercial nonphysical research
8733	Noncommercial research organizations
8741	Management services
8742	Management consulting services
8743	Public relations services
8748	Business consulting, n.e.c.
8900	Services, n.e.c.
Transportation	
3511	Turbines and turbine generator sets
3519	Internal combustion engines, n.e.c.
3566	Speed changers, drives, and gears
3568	Power transmission equipment, n.e.c.
3714	Motor vehicle parts and accessories
3731	Ship building and repairing