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THE EFFECT OF PUBLIC CAPITAL ON THE PRODUCTIVITY – AN ANALYSIS ON THE U.S. HIGHWAY STOCK*

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This paper estimates the elasticities of highway stock and maintenance spending by the growth accounting method. In addition, the continuous effects of highway stock and maintenance spending were examined. Highway stock has a positive, substantially large, and continuous effect on the private productivity, while maintenance spending, as a factor enhancing the effectiveness of highway stock, has an insignificant and negligibly small positive effect. Therefore, the productivity boost effect from road service comes mainly from the amount of highway stock rather than the effectiveness through maintenance spending.

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I. INTRODUCTION

The U.S. experienced a serious decline in the growth rate of the productivity during the 1970s, which occurred in most Western European countries also. Although the slowdown of the productivity occurred with the temporary oil shock, it has a permanent effect on the productivity which lasted quite long over the 1980s. The U.S. annual average productivity growth rate decreased from 1.5% in the period from 1968 to 1973 to 0.4% in the period from 1973 to 1986 (Fischer 1988). In a recent

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research with a longer time span data set, Nordhaus (2004) also confirmed the significance of the productivity slowdown of the 1970s by comparing the patterns of several different measures for productivity. He argued that the slowed productivity growth in the 1970s rebounded only in 1995, after the transition economy made a from energy-intensive production to electronic-intensive production. In terms of size and duration of the decline, it seems that the U.S. productivity slowdown of the 1970s is a major distinguishing feature of the 20th century.[1]

Correspondingly, many researchers tried to examine the causes of the productivity slowdown of the 1970s by examining energy prices, social regulation, the composition of the work force, R&D, an increase in the rate of depreciation of private capital, industry structure, and so on, but there have been no consisfently satisfactory explanations. In addition, previous analysis of the U.S. productivity slowdown has largely ignored the role of public capital (Gramlich 1994).

Aschauer (1989) argued that the neglect and low growth of public capital may be a crucial factor for the productivity slowdown and his research created the *public capital hypothesis*, which states that public capital has a significant positive effect on productivity. He reported a substantially large elasticity of public capital, 0.39. Since the early 1990s, many researchers provided supporting evidence for the public capital hypothesis by measuring the impact of public capital stock on productivity and examined policies to increase investment in new public capital.

In the empirical study of the link between public capital and productivity, highway stock has been the main focus among many kinds of public capital because highway stock is the largest component of public capital. Roughly, investment in the new highway stock was high in the 1950s and the 1960s and then has declined since the early 1970s after the U.S. interstate highway system was completed.

Currently, the quantity of *maintenance spending* is substantial, and it is a large portion of highway spending. The portion of investment in the new highway stock in total highway spending was 7.55% in 1997, while

[1] It is comparable to 1997 Asian financial crisis. Korea has experienced a continuous decline in potential GDP growth rate since then, although the growth rate in Korea has been positive in nearly all quarters since 1999.

that of maintenance spending is 20.6% (The Federal Highway Administration 2001 Report).

Maintenance spending may provide a positive effect on productivity, because maintenance spending can improve the quality of highway service and reduce the depreciation rate of the existing highway stock. Hulten (1996) and Rioja (2001) argued that maintenance spending has a substantial effect on productivity. Using cross-sectional country data, Hulten also showed that the effective use of infrastructure resources is more important than new investment in public capital for production growth. Using calibrated parameter values, Rioja also argued that reallocation of investment in new infrastructure toward maintenance of existing infrastructure has a positive effect on production. Hulten devised an effectiveness or quality measure of public capital stock, called the "embodied technical efficiency" measure. Similarly, Rioja posited that maintenance spending decreases the depreciation rate of existing capital stock and thus increases the existing highway stock over time.

But constructing these effectiveness measures is empirically challenging and demands great care. Both effectiveness measures have measurement error.

In this paper, I try to address three questions with regard to public capital hypothesis. First, does highway stock have a positive effect on productivity? Second, does maintenance spending also boost productivity? Third, to the degree that highway stock has a positive effect on the productivity, is its effect continuous or are there abrupt changes?

Similar to previous work, this paper postulates that maintenance spending enhances the effectiveness and quality of highway stock. The change in highway stock comes mainly from new construction and depreciation, which depends largely upon road usage and physical components. Maintenance spending, usually offsets depreciation to keep highways serviceable, and delivers better road service with improved highway design without increasing the amount of highway stock. In other words, maintenance spending does not increase the amount of highway stock, but boosts the highway service for the same amount of highway stock. We consider the direct effect of maintenance spending on productivity.

Hulten and Schwab (1991) and Fernald (1999) used the growth accounting to assess the link between productivity and public capital. Hulten and Schwab showed that public capital has no significant common external effect on productivity, while Fernald showed that highway stock has a positive effect on productivity and vehicle intensive industries benefit more from highway stock. Fernald, also argued that the massive road and highway building effort of the 1950s and 1960s in the U.S. was a one-time event that boosted the productivity growth during only that period. Thus, he claimed that maintence spending on an established network of highways are unlikely to have a large impact on production.

Chapter 2 describes the estimation method, the estimation issues, and data set. I employ the growth accounting method and I incorporate the value of highway stock and maintenance spending in a production function. I also discuss pooling data and the structure of the error in the estimation. Chapter 3 presents the estimation results. Chapter 4 concludes.

II. ESTIMATION METHOD, ESTIMATION ISSUES, AND DATA

This paper uses a growth accounting method with a panel set of industry data and is able to control for the time series properties of error terms due to the long series.

I estimate seperately the effects of highway stock and maintenance spending on productivity. Specifically, I calculate the elasticies of highway stock and maintenance spending after measuring the intensity of vehicle use.

2.1 Growth Accounting Method

The growth accounting method assumes a stable relationship between output and inputs represented as a production function, but I do not attempt to estimate parameters of a specific function. Rather, I derive the growth equation associated with a general production function and estimate the elasticities. This approach has two advantages because I do not need to assume a specific production function, and the number of parameters to be estimated is relatively small.

I consider a production function as follows,

$$Y_i = A_i F_i(K_i, L_i, I_i, E_i) \tag{1}$$

where Y_i denotes real gross output, K_i capital, L_i labor, I_i intermediate materials, and E_i energy input of industry i.[2] A_i is an unobservable Hicks neutral technology. By differentiating this function and dividing it by Y_i, I obtain the following growth equation

$$\frac{dY}{Y} = \frac{dA}{A} + \frac{AF_K K}{Y}\frac{dK}{K} + \frac{AF_L L}{Y}\frac{dL}{L} + \frac{AF_I I}{Y}\frac{dI}{I} + \frac{AF_E E}{Y}\frac{dE}{E} \tag{2}$$

where AF_K denotes the marginal productivity of privately owned capital, AF_L the marginal productivity of labor, AF_I the marginal productivity of intermediate materials, and AF_E the marginal productivity of energy input. d is the total differentiation operator.

The marginal productivity of inputs are unobservable. Under the assumptions of the profit maximization and competitive industries, each input is paid according to its marginal productivity. So I replace unobservable marginal productivities with observable input prices and rearrange the growth equation (2), to represent the growth rate of unobservable technology, or unobservable "multifactor productivity":

$$\frac{dA}{A} = \frac{dY}{Y} - S_K\frac{dK}{K} - S_L\frac{dL}{L} - S_I\frac{dI}{I} - S_E\frac{dE}{E} \tag{3}$$

where S_K denotes the share of capital, S_L the share of labor, S_I the share of intermediate materials, and S_E the share of energy input. With data on the shares of inputs and the growth rates of output and inputs, we can derive the rate of change of multifactor productivity, $\frac{dA}{A}$. The multifactor productivity, often called the Solow residual, is usually interpreted as the rate of change of technological progress. Equation (3) shows that this productivity growth reflects contributions from factors

[2] I omit time subscript for simplicity.

other than private inputs because shares of inputs reflect the productivity of public capital.

In order to examine the effect of public capital, we extend the production function by incorporating highway stock as an unpaid input

$$Y_i = A_i(G)F_i(K_i, L_i, I_i, E_i) \tag{4}$$

where G denotes effective highway stock.[3] When we include highway stock in the production function, we assume that the effective highway stock is a part of unmeasurable multifactor productivity rather than an explicit input of production, like the stock of privately owned capital.[4] Generally, highway service is provided free of charge, or at a subsidized cost, and firms do not perceive highway stock as a privately owned input of production. However, highway stock can influence productivity, since transportation of goods and services is a necessary part of a private enterprise, private property economy.

Accordingly, we posit that the multifactor productivity depends on the effective highway stock as follows,

$$\frac{dA_i}{A_i} = \eta_i \frac{dG}{G} + \varepsilon_{it} \tag{5}$$

where η_i denotes the elasticity of multifactor productivity for industry i with respect to the effective highway stock to industry i, ε_{it} the random error term, and $\frac{dG}{G}$ the growth rate of the effective highway stock. The random error term, ε_{it}, includes everything else that is related to multifactor productivity, except the effective highway stock. There may be a third factor such as R&D that raises highway stock and multifactor productivity simultaneously. If we omit this factor in the estimation, it could cause an endogeneity problem and make the estimate biased and imprecise.[5] As a result, we control for industry and time specific effects

[3] Modeling effective highway stock is discussed later.

[4] The production function approach treats public capital as an input.

[5] One of two anonymous referees pointed out this aspect. To deal with the endogeneity problem caused by omitting a third factor, we have use an instrument to estimate the explanatory variable.

of the error term, two factors that may affect highway stock and multifactor productivity simultaneously.

From equation (2), we can see that the growth rate of production, $\frac{dY}{Y}$, is proportional to the rate of change of multifactor productivity, $\frac{dA}{A}$, by a factor of one. Therefore, effective highway stock affects production by the same degree.

As we see in equation (5), each industry can use the productive services of the highway stock differently. We expect that if highway services are productive, industries that use highways intensively should benefit more. If the elasticity of highway stock is small for some industries, then we infer that these industries use highways less intensively so that highway services do not contribute much to the industry-specific multifactor productivity. To measure the industry-specific elasticity of highway stock, we must should measure highway usage by industry.[6] However, I do not have a direct highway usage measure by industry. Therefore, I decompose the elasticity of the effective highway stock into the ratio of the productivity of highway stock to vehicle stock and the ratio of vehicle stock to output. When the error term in (5) is insignificant,

$$\eta_i = \frac{AF_G G}{Y_i} = \left(\frac{AF_G G}{V_i}\right)\left(\frac{V_i}{Y_i}\right) = \phi_i s_i \tag{6}$$

where V_i denotes vehicle stock of industry i, and we define $\phi_i = \frac{AF_G G}{V_i}$, and $s_i = \frac{V_i}{Y_i}$.[7] The unobservable parameter, ϕ_i, is the key parameter linking the observable vehicle output ratio, s_i, to the unobservable elasticity of multifactor productivity with respect to effective highway stock, η_i. Because of the complementary relationship between vehicle stock and highway stock, the vehicle output ratio, s_i, which is the vehicle

Finding out a suitable instrument is a difficult task.

6 There is also an econometric reason to adjust highway stock with a highway usage measure. I discuss this issue in detail in the next section.

7 This method is similar to Fernald’s (1999). His method requires the vehicle price data but the decomposition in this paper does not require the vehicle price data.

intensity measure, is used to represent highway usage. By substituting equation (6) into equation (5), I obtain the following equation

$$\frac{dA_i}{A_i} = \phi_i \left(s_i \frac{dG}{G} \right) + \varepsilon_{it} \tag{7}$$

where $s_i \frac{dG}{G}$ denotes the adjusted growth rate of the effective highway stock of industry *i*. The unobservable parameter, ϕ_i, captures the effect of the adjusted effective highway stock on the multifactor productivity of industry *i*.

I assume that each industry's benefit from highway stock and maintenance spending is proportional to its vehicle intensity. I also assume that the effects of the adjusted highway stock and maintenance spending relative to vehicle intensity are equal across industries, $\phi_i = \phi$. The parameter, ϕ, represents the productive effect of highway stock and its constant value is consistent with the ides that vehicle intensive industries benefit more from highway services. By assuming that the productive effect of highway stock is constant across industries, the decomposition of the elasticity of effective highway stock in equation (6) becomes,

$$\eta_i = \phi s_i \tag{8}$$

and we obtain the following from equation (7)

$$\frac{dA_i}{A_i} = \phi \left(s_i \frac{dG}{G} \right) + \varepsilon_{it} . \tag{9}$$

I expect that ϕ is positive, which characterizes the notion that highway is productive.

To measure the effectiveness of highway stock, I use maintenance spending. Service from highway stock are derived from its effectiveness as well as its quantity. To measure the productivity or effectiveness of highway stock. I define

$$G = M^{\theta} H \tag{10}$$

where M denotes maintenance spending and H highway stock. The unobservable parameter, θ, captures the effectiveness of maintenance spending in changing the productivity of highway stock. If it positive, maintenance spending is at least somewhat effective. Diminishing marginal productivity or effectiveness of maintenance spending implies that, θ, is less than 1.

A one period lagged variable is used to measure public capital because newly built highways provides the service in the future. However, current maintenance spending is used to measure effectiveness or productivity of existing highway stock, because it enhances the service from existing highway stock in the current period.

From the formulation of the effective highway stock in equation (10), the growth rate of the effective highway stock is represented as follows,

$$\frac{dG}{G} = \theta \frac{dM}{M} + \frac{dH}{H} \tag{11}$$

where $\frac{dM}{M}$ denotes the growth rate of maintenance spending and $\frac{dH}{H}$ the growth rate of highway stock. By substituting equation (11) into equation (9), we obtain the estimation equation that includes maintenance spending as follows,

$$\frac{dA_i}{A_i} = \varphi\theta\left(s_i \frac{dM}{M}\right) + \varphi\left(s_i \frac{dH}{H}\right) + \varepsilon_{it}\,. \tag{12}$$

where $s_i \frac{dM}{M}$ denotes the adjusted growth rate of maintenance and $s_i \frac{dH}{H}$ the adjusted growth rate of highway stock of industry *i*.

Equation (12) provides the baseline estimation equation in this chapter. The effect of the adjusted highway stock, ϕ, and that of the adjusted maintenance spending, $\phi\theta$, are estimated separately, therefore both ϕ and θ can be identified. With the average vehicle intensity of the economy, $\bar{s}$, I obtain the elasticity of highway stock, $\phi\bar{s}$ and that of maintenance spending, $(\phi\theta)\bar{s}$. I use the share of output by industry as an industry weight.

Fernald (1999) argued that additional highway stock does not provide marginal benefit after a complete network has been built. He incorporated the change in the coefficient of highway stock to estimate the marginal impact of highway stock after the highway system was completed. To examine whether highway stock and maintenance spending have only a one-time effect, I also included the change in the coefficients of highway stock and maintenance spending in equation (12) and obtained the following equation,

$$\frac{dA_i}{A_i} = \phi\theta\left(s_i \frac{dM}{M}\right) + \phi\left(s_i \frac{dH}{H}\right) + (\phi\theta)_{73} D\left(s_i \frac{dM}{M}\right) + \phi_{73} D\left(s_i \frac{dH}{H}\right) + \varepsilon_{it} \tag{13}$$

where D is a indicator variable that assigns 1 to the period from year 1973 and 0 to the period before year 1973. Thus the indicator variable, D, captures the structural change after year 1973.[8] The parameters ϕ_{73} and $(\phi\theta)_{73}$ represent the time-specific effects of the changes in highway stock and maintenance spending, respectively. I obtained the elasticities of the changes in highway stock and maintenance spending similarly with the average vehicle intensity.

I calculated the growth rates of each variable by approximating them to differences of the log variables in two consecutive years as follows,

$$\frac{dX_{it}}{X_{it}} \approx \log X_{it+1} - \log X_{it} \tag{14}$$

and derived the growth rate of the multifactor productivity by equation (3).

[8] 1973 is the traditional dating of the productivity slowdown.

2.2 Estimation Issues

2.2.1 Nonstationarity, Endogeneity, and Convergence Problems

Recent researchers estimated the elasticity of public capital by using disaggregate data, controlling for *nonstationarity* and *endogeneity* problems. Generally aggregate data produce increasing (that is, nonstationary) estimates over time. Nonstationary estimates may generate a *spurious relationship* (Aaron 1990, Tatom 1991b). First differenced variables are supposed to account for nonstationarity variables.[9]

Disaggregate data also resolves the issue of causality between productivity and public capital. Usually the causality runs on both directions so that estimation using aggregate data causes an *endogeneity* problem (Eisner 1990, Tatom 1991a, and Tatom 1993).[10] At the industry level, however, we may theorize that public capital causes productivity rather than vice versa. By its nature, public capital is created outside of an industry, even though private firms in each industry benefit from it.

In addition, analysis with disaggregate industry data is free from the problem caused by convergence. That is a problem with disaggregate regional or state data. Annala (2000, 2003) and Couglin et al. (2006) showed most fiscal policy variables from states tend to converge. Convergence among states reduces the variability of public capital across states and therefore would reduce the estimated effect of public capital. That is, convergence makes it difficult to assess the link between the effective highway stock and productivity when using state level data. So, estimation with disaggregate industry data is one suitable direction to assess the link of the effective highway stock and the productivity.

2.2.2 Data Pooling and Adjustment of the Effective Highway Stock

Every industry faces equal amounts of highway stock and maintenance spending provided by the government externally. Therefore, highway stock and maintenance spending can generate the similar effects on

[9] Munnell (1992) opposed the first differencing, arguing that it destroys the long-run relationship. She proposed the estimation by the error correction model, which takes into account the long-run relationship of the cointegrated variables.

[10] We can adopt the vector autoregressive (VAR) model to control for the endogeneity in aggregate data analysis. Batina (1998) showed a supporting evidence for the U.S. data, and Kang (2006) for Korean data by taking a VAR model.

productivity across industries, although I expect that the effects of highway stock and maintenance spending are different across industries due to the different intensities of highway usage. That is, correlation exists between productivity and vehicle intensity among different industries.

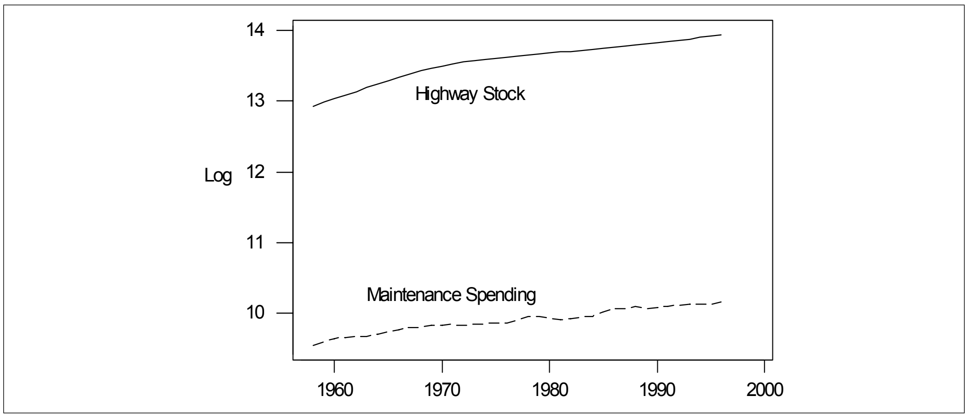
This correlation necessitates a data-pooled estimation. One general data pooling method is the estimation by the seemingly unrelated regression (SUR), but the SUR method is inappropriate in this analysis. Applying the SUR method is equivalent to estimating a separate equation by each industry, because each equation by industry contains the same variables. Thus, data pooling by the SUR method provides no benefit, so I consider more restricted data pooling.

When using disaggregate industry data, one must adjust highway stock and maintenance spending by industry since. Multifactor productivity, varies across industries, but highway stock and maintenance spending do not vary across industries. Without adjustment, this limited variability of highway stock and maintenance spending causes inefficient, thus imprecise estimates. If we adjust highway stock and maintenance spending with a highway usage measure by each industry, the adjusted effective highway stock varies proportionately to the highway usage measure by industry.

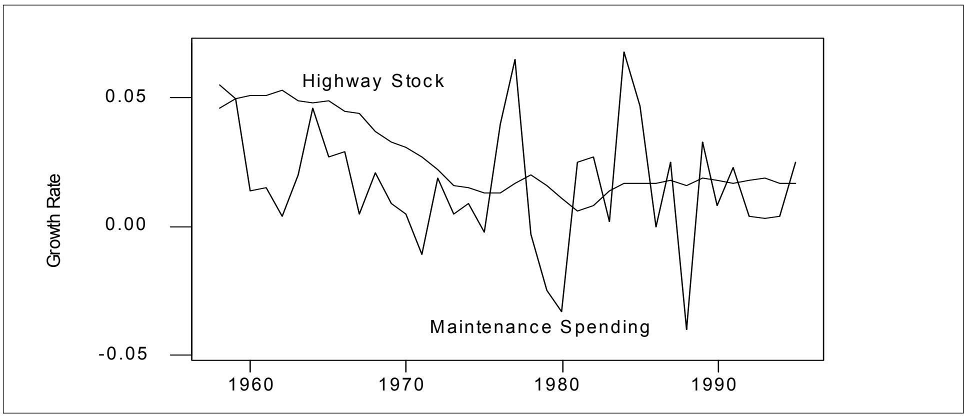
To restrict the pooled data more than by the SUR method, we assume the adjusted highway stock has the same effect on productivity across industries but each industry's response to the effective highway stock varies only by the highway usage measure. By this assumption, I can achieve data pooling and gain the variability of highway stock and maintenance spending by industry.

As we observe in Figure 1, highway stock and maintenance spending show the similar upward trends, and they may be nonstationary. Figure 2 shows the time trends of the first differenced highway stock and maintenance spending for the period from 1958 to 1995, which are equivalent to the growth rates of the variables. Highway stock increased rapidly in the 1950s and 1960s, while it increased slowly after the 1970s. For maintenance spending, there is no obvious time trend. The time trends of the adjusted highway stock shows a the downward trend in most industries, while the adjusted maintenance spending show no obvious time trend in any industry. The adjusted highway stock has the downward trend because the trend of the unadjusted highway stock dominates the trend of the vehicle intensity measure.

[Figure 1] Time Trends of Highway Stock and Maintenance Spending Level



[Figure 2] Time Trends of the Growth Rates of Highway Stock and Maintenance Spending



2.2.3 Error Structure

The panel data permits greater flexibility to specify the error term. I specify the error term as follows,

$$\varepsilon_{it} = f_i + \gamma_t + \mu_{it} \tag{15}$$

where f_i is an industry specific component, γ_t is a time specific component, and μ_{it} is an independently and identically distributed error tern across industries and term. The industry specific component captures the specific characteristics in each industry which are unobservable or omitted from the equation but do not vary over time, while the time specific component controls for unobservable or omitted effects which are common to all industries in each time period.[11]

f_i and γ_t are correlated with explanatory variables. If I omit these components, the estimates of coefficient are biased and the estimate of variance is biased upward. Thus, controlling for the industry and time specific effects provides more precise estimates.

Indirectly we have already controlled for these effects with the vehicle intensity measure, s_i. The vehicle intensity measure partially controls for the industry specific effect as well as time effects, because the vehicle usage varies across industries and across time cycle.

2.3 Data

Jorgenson provided the data for private input and outputs (35klem96.dat). The data include values and prices of output and inputs in current values for 35 industries of the U.S. economy from 1958 to 1996. Values are in millions of current dollars and prices are normalized to 1 in 1996. By dividing nominal values of output and inputs by their prices, we can obtain real values for output and inputs in 1996 dollars.

Jorgenson developed these data by using a combination of industry data from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS). The data include gross output, and inputs of capital, labor, energy, and intermediate materials. [12] I use labor hours as a proxy for labor input. The industries in the data set cover the entire U.S. economy. The classification of industries corresponds approximately to the 2-digit standard industrial classification (SIC). I obtained industry vehicle stock data from the BEA gross domestic product by industry and

[11] These components are treated as fixed effects, because the industries are not chosen randomly.

[12] Jorgenson and Stiroh (2000) described their methodology on estimating their industry input and output data.

[Table 3.1] Multifactor Productivity Growth Rate and Vehicle Intensity by Industry

Industry	(1) Average MFP Growth Rate 1958-1995	(2) Average MFP Growth Rate 1973-1995	(3) Average MFP Growth Rate 1958-1972	(4) Average Vehicle Intensity 1958-1995	(5) Average Vehicle Intensity 1973-1995	(6) Average Vehicle Intensity 1958-1972
Agriculture	0.017	0.015	0.020	0.080	0.086	0.072
Metal mining	0.007	-0.004	0.020	0.107	0.167	0.016
Coal Mining	0.025	0.025	0.027	0.026	0.037	0.010
Oil and gas extraction	0.005	-0.009	0.029	0.021	0.026	0.014
Non-metallic mining	0.016	0.002	0.033	0.053	0.068	0.030
Construction	0.014	0.007	0.031	0.020	0.024	0.013
Food and kindred products	0.022	0.031	0.025	0.009	0.008	0.009
Tobacco	0.004	-0.004	0.013	0.002	0.003	0.001
Textile mill products	0.024	0.014	0.040	0.004	0.004	0.003
Apparel	0.022	0.009	0.043	0.004	0.004	0.003
Lumber and wood	0.024	0.012	0.045	0.022	0.027	0.015
Furniture and fixtures	0.030	0.018	0.030	0.008	0.009	0.006
Paper and allied	0.030	0.017	0.046	0.008	0.007	0.009
Printing, publishing and allied	0.026	0.020	0.034	0.006	0.006	0.005
Chemicals	0.035	0.016	0.064	0.006	0.005	0.007
Petroleum and coal products	0.022	0.014	0.039	0.004	0.005	0.002
Rubber and miscellaneous plastics	0.053	0.032	0.084	0.004	0.005	0.004
Leather	-0.020	-0.030	-0.002	0.003	0.004	0.002
Stone, clay, glass	0.018	0.004	0.036	0.037	0.038	0.035
Primary metal	0.010	-0.011	0.034	0.005	0.005	0.006
Fabricated metal	0.023	0.007	0.041	0.006	0.006	0.005
Machinery, non-electrical	0.047	0.013	0.048	0.007	0.007	0.007
Electrical machinery	0.055	0.042	0.069	0.007	0.006	0.010
Motor vehicles	0.037	0.018	0.057	0.004	0.003	0.004
Transportation equipment and ordnance	0.013	0.007	0.013	0.004	0.004	0.004
Instruments	0.054	0.043	0.065	0.005	0.005	0.004
Miscellaneous manufacturing	0.026	0.009	0.055	0.006	0.007	0.004
Transportation	0.033	0.026	0.040	0.125	0.140	0.101
Communications	0.051	0.045	0.059	0.056	0.053	0.060
Electric utilities	0.037	0.023	0.058	0.036	0.045	0.023
Gas utilities	0.006	-0.025	0.059	0.050	0.060	0.034
Trade	0.037	0.031	0.047	0.033	0.039	0.023
Finance Insurance and Real Estate	0.035	0.031	0.042	0.026	0.036	0.011
Services	0.045	0.035	0.061	0.028	0.032	0.021
Economy Average	0.004	0.002	0.007	0.024	0.028	0.019
Time Mean of Standard Deviation	0.0006	0.0007	0.0004	0.0055	0.0068	0.0034

the components of the gross domestic income series from 1947 to 2000. The government enterprise industry in Jorgenson's data was excluded from the analysis because vehicle stock data for that industry is unavailable.

Highway stock data came from the BEA fixed asset series from 1925 to 2001, and maintenance spending data from 1929 to 2000 came from the Federal Highway Administration (FHWA). Both highway stock and maintenance spending are in 1996 dollars.

In Figure 2, we can observe the time trends of the growth rates of highway stock and maintenance spending from 1958 to 1995. The average growth rate of highway stock is 2.703% from 1958 to 1995, 1.564% from 1973 to 1995, and 4.556% from 1958 to 1972.

For maintenance spending, there is no obvious time pattern. The average growth rate of maintenance spending is 1.584% from 1958 to 1995, 1.299% from 1973 to 1995, and 2.007% from 1958 to 1972.

Table 3.1 reports the average growth rate of multifactor productivity and the average vehicle intensity by industry. In all industries except for the food industry, the average multifactor productivity growth rate is higher before 1973, possibly, due to diminishing marginal productivity. In contrast, the growth rate of average vehicle intensity is larger after 1973. This fact indicates that vehicle transportation has become more important in the production and sale of goods and services.

III. ESTIMATION RESULTS

3.1 Estimation Results for the Full Data Set

I did unit root tests for each variable by industry, by applying both the augmented Dickey-Fuller test (ADF test) and the Phillips-Perron test (PP test). Unit root testing indicates that the variables are integrated of different orders. The growth rate of the multifactor productivity is $I(0)$ in every industry. The adjusted growth rate of highway stock is $I(1)$, thus nonstationary, except for that of the electrical machinery industry. In the electrical machinery industry, the adjusted growth rate of highway stock is $I(0)$. The adjusted growth rate of maintenance spending is $I(0)$ in every industry.

To take into account the nonstationarity of the adjusted growth rate of highway stock, I considered including the lagged values in the estimation equations, but this method was ineffective. The appropriate lag order is not determined by the lag minimizing information criteria, because the information criteria decreased as the lag order decreases. Thus, I used the one period lagged variable for the growth rate of the adjusted highway stock and identified the serial correlation of the error term in the estimation equations.

Table 3.2 reports the estimation results from 1958 to 1995. The estimates of parameters ϕ and $\phi\theta$ represent the effects of highway stock and maintenance spending on productivity, respectively. With the average vehicle intensity of the economy, $\bar{s}$, I derive the elasticity of highway stock, $\phi\bar{s}$, and of maintenance spending, $(\phi\theta)\bar{s}$. The average vehicle intensity of the economy is 0.024 from 1958 to 1995. The first four columns report the results when maintenance spending is excluded from the estimation and the second four columns report the results when maintenance spending is included in the estimation. The presence of maintenance spending decreases the elasticity of highway stock slightly, which suggests that previous research, may have overstated the effect of public capital by not considering maintenance spending.

[Table 3.2] Estimation Results for the Sample Period from 1958 to 1995

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS 1	IND 1	TIME 1	TWO WAY 1	OLS 2	IND 2	TIME 2	TWO WAY 2
ϕ	3.985 (0.0062)	8.137 (<0.0001)	4.359 (0.0036)	10.593 (<0.0001)	3.133 (0.0393)	4.250 (0.0070)	4.067 (0.0114)	9.833 (<0.0001)
$\phi\theta$	-	-	-	-	2.393 (0.0017)	1.384 (0.1132)	1.364 (0.1187)	1.431 (0.0991)
$\phi\bar{s}$	0.0956	0.1953	0.1046	0.2542	0.0752	0.1020	0.0976	0.2360
$(\phi\theta)\bar{s}$	-	-	-	-	0.0574	0.0332	0.0327	0.0343
θ	-	-	-	-	0.7638	0.3256	0.3354	0.1455
AR Order	AR (12)	AR (24)	AR (12)	AR (18)	AR (10)	AR (10)	AR (10)	AR (18)
Industry Effects	NO	YES	NO	YES	NO	YES	NO	YES
Time Effects	NO	NO	YES	YES	NO	NO	YES	YES

a. The P-values in parenthesis.

b. The weighted average vehicle intensity of the economy, $\bar{s}$, is 0.024.

In the first four columns of Table 3.2, there are three noticeable results. First, the estimate for highway stock, ϕ, is positive and highly significant, regardless of the industry or time specific effect. The elasticity of highway stock, $\phi\bar{s}$, ranges from 0.0956 to 0.2542, depending on the industry and time specific effects. Second, controlling for industry specific effect increases the elasticity more than two times. Third, controlling for time specific effect also increases the elasticity slightly. The elasticity of highway stock is 0.0956 in column 1 and 0.1046 in column 3, while it is 0.1953 in column 2 and 0.2542 in column 4.

The second four columns of Table 3.2 report the results when maintenance spending is included in the estimation. And show similar patterns to those in the first four columns. First, the estimate for highway stock, ϕ, is positive and highly significant, regardless of the industry or time specific effect. The elasticity of highway stock, $\phi\bar{s}$, ranges from 0.0752 to 0.2360, depending on the industry and time specific effects. Second, controlling for industry specific effect increases the elasticity considerably. Third, controlling for time specific effect also increases the elasticity slightly. The elasticity of highway stock is 0.0752 in column 5 and 0.0976 in column 7, while it is 0.1020 in column 6 and 0.2360 in column 8.

The estimate for maintenance spending, $\phi\theta$, is also positive, regardless of the industry or time specific effect. The elasticity of maintenance spending, $(\phi\theta)\bar{s}$, ranges from 0.0327 to 0.0574, depending on the industry and time specific effects. However, the estimate is insignificant at the 5% significance level, except for the estimate in column 5 where the p-value is 0.0017.

The most preferable model is TWO WAY 2 of column 8 because it controls for both the industry and the time specific effects. The elasticity of highway stock is 0.2360 (0.024×9.833) and that of maintenance spending is 0.0343 (0.024×1.431). The elasticity of maintenance spending is positive but small. The effectiveness of maintenance spending is 0.1455 (1.431/9.833). These results indicate that highway stock is substantially productive but maintenance spending is slightly productive. Thus, the productivity boost of the effective highway stock comes mainly from the quantity of highway stock rather than the effectiveness of highway stock through maintenance spending.

3.2 Structural Change after 1973

I estimated the effects of the changes in highway stock and maintenance spending on the productivity to examine whether highway stock and maintenance spending have just a one-time effect on productivity. Equation (13), in which the changes in the coefficients of highway stock and maintenance spending are included, provides the estimates for the changes in highway stock and maintenance spending.[13]

Table 3.3 reports the estimation results for the case that the structural change occurs only in highway stock. In the first four columns, maintenance spending is excluded from the regression. In the second four columns, maintenance spending is included in the estimation. The presence of maintenance spending decreases both the estimates for highway stock and those for the change in highway stock slightly.

[Table 3.3] Estimation Results for the Change of Highway Stock

	(1) OLS 1	(2) IND 1	(3) TIME 1	(4) TWO WAY 1	(5) OLS 2	(6) IND 2	(7) TIME 2	(8) TWO WAY 2
ϕ	2.304	8.183	0.953	7.771	1.046	7.367	0.431	7.405
	(0.1570)	(<0.0001)	(0.6081)	(<0.0001)	(0.5305)	(<0.0001)	(0.8202)	(0.0002)
$\phi\theta$	-	-	-	-	2.036	2.078	0.934	0.827
					(0.0081)	(0.0074)	(0.2889)	(0.3472)
ϕ_{73}	6.911	9.887	9.094	11.560	5.604	8.957	8.578	11.230
	(0.0019)	(<0.0001)	(0.0011)	(<0.0001)	(0.0157)	(<0.0001)	(0.0024)	(<0.0001)
$\phi_{73}\bar{s}$	0.1935	0.2768	0.2546	0.3239	0.1569	0.2508	0.2402	0.3144
AR Order	AR (15)	AR (18)	AR (13)	AR (18)	AR (12)	AR (18)	AR (12)	AR (18)
Industry Effects	NO	YES	NO	YES	NO	YES	NO	YES
Time Effects	NO	NO	YES	YES	NO	NO	YES	YES

a. The P-values in parenthesis.

b. The weighted average vehicle intensity of the economy, $\bar{s}$, is 0.028.

[13] The test statistics for the structural change are not known, because the regressions take into account the serial correlation of the error term. For the regressions that do not control for the serial correlation, the Chow tests suggest that there is a structural change after 1973. In most cases, the F-value is greater than the critical value at the 1% significance level.

The effect of the change in highway stock is substantially large. The estimate for the change in highway stock, ϕ_{73}, is positive and significant, regardless of the industry or time specific effect. Controlling for the industry specific effect increases the estimate considerably. The estimates in the even columns are larger than those in the odd columns. I derived the elasticity of the change in highway stock, $\phi_{73}\bar{s}$. The average vehicle intensity of the economy is 0.028 from 1973 to 1995. In the first four columns, the elasticity of the change in highway stock ranges from 0.1935 to 0.3239, depending on the industry and time period. In the second four columns, the elasticity of the change in highway stock ranges from 0.1569 to 0.3144, depending on the industry and time specific effects.

The estimate for highway stock, ϕ, represents the effect of highway stock before 1973, which is positive, regardless of the industry or time specific effect. Controlling for the industry specific effect increases the estimate and decreases the p-value substantially. The estimates in the even columns are much larger and significant than those in the odd columns. The estimates in the even columns are highly significant, while those in the odd columns are insignificant.

The estimate for maintenance spending, $\phi\theta$, is also positive, regardless of the industry or time specific effect. Controlling for the time specific effect decreases the estimates and increases the p-values substantially. The estimates in column 7 and column 8 are smaller than those in column 5 and column 6. The p-value is 0.2889 in column 7 and 0.3472 in column 8, while it is 0.0081 in column 5 and 0.0074 in column.

Table 3.4 reports the estimation results if a structural change occurred in 1973 in both highway stock and maintenance spending. I see that the change in highway stock is large and positive in this case. Regardless of the industry or time specific effect, it is significant, except for that in column 1 where the p-value is 0.1661. Controlling for the industry specific effect increases the estimate and decreases the p-value. Controlling for the time specific effects also increases the estimate. The estimate is 6.685 in column 2 and 10.758 in column 4, while it is 3.979 in column 1 and 8.575 in column 3. The p-value is 0.0089 in column 2 and 0.0006 in column 4, while it is 0.1661 in column 1 and 0.0149 in column 3. The elasticity of the change in highway stock, $\phi_{73}\bar{s}$, ranges from

0.1114 to 0.3012, depending on the industry and time specific effects.

The estimate for the effect of the change in maintenance spending, $(\phi\theta)_{73}$, is positive, regardless of the industry or time specific effect. The estimate, however, is highly insignificant, regardless of the industry or time specific effect. Controlling for the industry specific effect increases the estimate and decreases the P-value. On the contrary, controlling for the time specific effect decreases the estimate and increases the p-value. The estimate is 5.487 in column 2 and 1.113 in column 4, while it is 3.871 in column 1 and 0.010 in column 3. The p-value is 0.1746 in column 2 and 0.8212 in column 4, while it is 0.3366 in column 1 and 0.9983 in column 3. The elasticity of maintenance spending by the change, $(\phi\theta)_{73}\overline{s}$, ranges from 0.0003 to 0.1536, depending on the industry and time specific effects. It seems that the effect of the change in maintenance spending is insignificant and negligibly small.

[Table 3.4] Estimation Results for the Changes of Highway Stock and Maintenance Spending

Variable	(1) OLS 1	(2) IND 1	(3) TIME 1	(4) TWO WAY 1
ϕ	2.631 (0.2610)	9.707 (0.0001)	0.436 (0.8741)	7.868 (0.0062)
$\phi\theta$	-1.681 (0.6702)	-3.202 (0.4189)	0.923 (0.8479)	-0.239 (0.9605)
ϕ_{73}	3.979 (0.1661)	6.685 (0.0089)	8.575 (0.0149)	10.758 (0.0006)
$(\phi\theta)_{73}$	3.871 (0.3366)	5.487 (0.1746)	0.010 (0.9983)	1.113 (0.8212)
$\phi_{73}\overline{s}$	0.1114	0.1872	0.2401	0.3012
$(\phi\theta)_{73}\overline{s}$	0.1084	0.1536	0.0003	0.0312
AR Order	AR (12)	AR (18)	AR (12)	AR (18)
Industry Effects	NO	YES	NO	YES
Time Effects	NO	NO	YES	YES

a. The P-values in parenthesis.

b. The weighted average vehicle intensity of the economy, $\overline{s}$, is 0.028.

The estimate for highway stock, ϕ, is positive, regardless of the industry or time specific effect. Controlling for the industry specific effect increases the estimate for highway stock and decreases the p-value substantially. On the contrary, controlling for the time specific effect decreases the estimate slightly. The estimate is 9.707 in column 2 and 7.868 in column 4, while it is 2.631 in column 1 and 0.436 in column 3. The P-value is 0.0001 in column 2 and 0.006 in column 4, while it is 0.2610 in column 1 and 0.8741 in column 3. The estimate for maintenance spending, $\phi\theta$, is negative, except for that in column 3. It is highly insignificant, regardless of the industry and time specific effect.

According to Table 3.3 and Table 3.4, there is a structural change only in highway stock and the effect of the change in highway stock is substantially large. I conclude that new highway stock is more important and has a continuous positive effect on productivity even after the network has been constructed.

This conclusion contrasts to Fernald's (1999), who concluded that the US highway network had only a one-time effect on productivity. He estimated the effect for several industry classification such as aggregate industry, one-digit industry, manufacturing industry and non-manufacturing industry. For each classification, his estimate is negative. All are insignificant, except for that for the aggregate industry. For the aggregate industry, the estimate is -25.3 and its standard error is 11.2.

In contrast, my results show that industries continue to benefit from the highway system even after it is completed. The trends of the growth rates of highway stock, multifactor productivity and vehicle intensity confirm this conclusion. The growth rates of highway stock and multifactor productivity were lower after 1973 than those in the previous period, and the decrease in the growth rate was larger for highway stock than for multifactor productivity. This implies that the change in highway stock after 1973 had a positive and continuous impact on productivity. The positive association between the adjusted growth rates of highway stock and the growth rate of multifactor productivity also supports this conclusion. The increase in vehicle intensity after 1973 offsets the large decrease in the growth rate of highway stock, which moderates the positive association between the adjusted growth rate of highway stock and the growth rate of multifactor productivity. Despite the moderated positive association, the estimates for the change in the adjusted highway stock is considerably large.

IV. CONCLUSION

Many economists have focused on the link between the amount of public capital and productivity but have ignored the role of maintenance spending. This paper models maintenance spending as a factor that enhances the effectiveness of or productivity from highway service.

I estimated the effects of highway stock and maintenance spending and derived the elasticities by using disaggregate industry data in a growth accounting model. Allowing for the complementary relationship between highway stock and vehicle stock, I decomposed the elasticities of highway stock and maintenance spending with the vehicle intensity measure by industry. I controlled for the nonstationarity of the adjusted growth rate of highway stock by taking into account the serial correlation of the error term. The estimation also controlled for the industry and time specific effects to allow for the properties of a panel data set.

The estimation results illustrate that both highway stock and maintenance spending have a positive effect on productivity but the boostin productivity from highway service comes mainly from the quantity of highway stock rather than from the effectiveness or quality through maintenance spending. According to the results from the most preferable model, highway stock has a significant and substantial positive effect on productivity. The elasticity of highway stock is 0.2360, and that of maintenance spending is 0.0343. The significance of the estimate for maintenance spending is mixed. The estimate of maintenance spending is insignificant when I control for the time specific effect with an indicator variable but is significant when I control for the time specific effect with the capacity utilization rate.

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