The contribution of Highway Capital to productivity Growth

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Aims

My aims for this presentation are:

- To give a brief literature review
- To provide an example of the problems and solutions given by the literature analyzing the relationship between state productivity and highway capital
- To show an alternative model which takes into account the heterogeneous and nonlinear effects of highway capital

Overview

- Government appears to want to increase public spending due to the financial crisis: a good candidate highway capital
- Highway funding was a major issue in the US. Discussions on how the revenues should be collected and where to be allocated
- Literature evidence show that the effect of highway capital on the production of the economy is generally positive and significant. An effect though that varies.
- In most studies, highway capital enters as a free input in the production function but recent literature gives more emphasis in the networking effect of highway capital, congestion and spillovers. They also point out that the choice of a functional form might restrict and bias the estimated elasticities.

Review

- Highway capital is a major component of public infrastructure and its characterized by substantial network externalities that benefit both producers and consumers.
- Even though the relationship between highway capital and productivity has not been investigated in depth, studies generally find positive and significant effects.
- There are numerous studies conducted at the national, regional, state or industry level using production or dual (cost, profit) functions.

Review

- At the aggregate level the effect of highway capital is found to be positive and significant (Mamuneas and Nadiri, 2003).
- At less aggregate level the effects are found to be smaller and varying (Nadiri and Mamuneas, 1996, 2000; Keeler and Ying, 1988) or be insignificant (Holtz-Eakin and Schwartz, 1995) depending on the unit under investigation, the data set and methods used.
- Studies incorporating spillover effects of highway capital as well as congestion also find mixed results that depend on the model specifications (Boarnet, 1998; Kelejian and Robinson, 1997; Cohen and Morrison Paul, 2004, Sachez-Robles, 1998, Fernald, 1999).
- Finally, the Cobb-Douglas and other specifications of the production function impose a priori restrictions that might bias the estimated elasticities. Therefore estimates based on these functional forms might bias the results due to model misspecification. Indeed, Henderson and Kumbhakar (2005) estimate a nonparametric production function by using a Li-Racine Generalized Kernel estimation and find positive and significant effects.

Motivation

- Most studies at the state level consider highway capital stock as a free input which has a constant output elasticity across states and over time.
- In contrast to the constant elasticities that are assumed, the effect of highway capital services might be heterogeneous and nonlinear and therefore the highway capital elasticities dependant on the level of highway capital stock, among other things.
- Recent literature gives more emphasis on the services provided by highway capital which might be subject to:

Motivation

- **Networking effect:** Once the basic links of a network are established, opportunities for high productive investment diminishes (Hulten and Scwab, 1993). The first infrastructure network gives the largest benefit but the subsequent investment becomes less productive.
- **Congestion effects:** More vehicles in one road reduce its productivity. More roads will reduce congestion but up to a certain threshold where after that marginal increases will have no effect on congestion (Sancez-Robles, 1998, Fernald, 1999)
- **Spatial Spillover effects:** Services can be used by a multitude of users located at different areas. Thus the benefits from an investment in a point of a network will depend on the capacities at other points (Holtz-Eakin and Schwrtz, 1995, Kelejian and Robinson,1997, Cohen and Morrison-Paul, 2004).
- All the above point out that there might be inherent nonlinearities involved with the provision of highway capital.

Objectives

- The objective of this paper is to model these nonlinearities using a cost function framework
- A TFP regression approach is employed that takes into account the networking, congestion and spillover effects.
- A smooth coefficient semi-parametric model (Fan and Zhang, 1999, Li et. al. , 2002) is applied in a newly constructed dataset for 48 US states in the period 1963-2011
- There is evidence consistent with nonlinearities associated with the productivity effects of highway capital.

Outline

- Data description
- The general model, that takes into account the nonlinearities due to networking, congestion and spillover effects
- Results
- Conclusions

Data

- The sample size refers to the 48 contiguous US states for the period 1963 to 2011.
- The units of measurement are millions of US dollars and the base year is 2004.
- The dataset includes: output, labor, physical capital, highway capital, spillovers of highway capital (spatial externalities) and congestion (approximated by vehicles-national miles of travel).
- Output is defined as Gross Domestic Product and labor is given in man-hours. Private capital stock was constructed using BEA national stock estimates of the sectors: Farm, Manufacturing, Nonfarm and Nonmanufacturing among the states, and the rental price of capital is defined by $W_K = PI\frac{(r+\delta)}{(1+r)}tax$

Data

- Highway capital outlay data (investment) per state were obtained from Governmental Finances and highway capital stock was constructed by the perpetual inventory method.
- Spillovers were constructed using the public capital and highway capital stocks. It is assumed that: $S_{it} = \sum_j w_{ij} G_{jt}$ where S_{it} is the public capital stock (or highway capital stock) of region j, w_{ij} is the weight of other regions capital (taking the value 1, for own state and for boarder state and 0 otherwise). We also use the distance between states as a weight matrix.
- Various specifications have been proposed in the literature for the congestion function. We follow Fernald (1999) and we use motor vehicles miles traveled. The data were obtained from the US Department of Transportation, Federal Highway Administration, Highway Statistics by functional system, and by state.
- Various sources were used to obtain the final dataset and the methodology followed is similar to Munnell (1992).

An illustration:

Consider the Cobb-Douglas specification:

$$\ln Y_{it} = a_t + a \ln K_{it} + \beta \ln L_{it} + \gamma H_{it} + u_{it} \tag{1}$$

, where Y, L, K and H are the output, labor, physical capital and highway capital, α, β, γ are the output elasticities of capital, labor and highway capital respectively, α_t measures productivity and u is the error term

An illustration: Results

Table 1: Cobb-Douglas Parameter Estimates (std. Errors)

Parameter	OLS	IV	Fixed Effect	Differencing -IV
ln H	0.40	0.218	0.031	0.157
	(0.021)	(0.009)	(0.022)	(0.032)
ln K	-0.33	0.118	-0.137	-0.042
	(0.025)	(0.003)	(0.021)	(0.058)
ln L	0.94	0.74	0.45	1.54
	(0.029)	(0.008)	(0.029)	(0.288)

Time Effects are included

An illustration: Results

- OLS results appear to be nonsense. The estimates are inconsistent and biased.
- Introducing Fixed effects, the results do not appear to improve.
- First differencing and instrumentation does not seem to fix the problem
- The effect of private capital appears negative in all three specifications and only the IV procedure offers positive results. Also one would expect that private capital will have a larger effect than highway capital.
- Also the results are sensitive to the choice of instruments.
- The elasticity of highway capital, due to networking, congestion and spillover effects might not be linear
- Below we present a model in which possible misspecification of the production function and more careful consideration of congestion, networking and spillover effects are taken into account.

The Model

Suppose that the technology of the firms in a state i at time t is given by the following Cost function:

$$C = C(w_{Lit}, w_{Kit}, Y_{it}, G_{it}, t) \tag{2}$$

Total differentiation with respect to time and division by C yields:

$$\hat{C}_{it} = \sum_{x=L,K} \frac{\partial C_{it}}{\partial w_{xit}} \frac{w_{xit}}{C_{it}} \hat{w}_{xit} + \frac{\partial C_{it}}{\partial Y_{it}} \frac{Y_{it}}{C_{it}} \hat{Y}_{it} + \frac{\partial C_{it}}{\partial G_{it}} \frac{G_{it}}{C_{it}} \hat{G}_{it} + \frac{\partial C_{it}}{\partial t} \frac{1}{C_{it}} \tag{3}$$

,where $\hat{}$ denotes a growth rate, w denotes variable input prices (labor and capital), Y is the output quantity, t is an index of time representing disembodied technical change and G is the highway capital services which might not be equal to the highway capital stock, H.

The Model

- The public capital services (highway) affect the cost structure via two ways.
- First, a larger or a better quality of these capital services will shift the cost per unit of output downwards in a firm, if the firm receives any benefits from improved or more capital services.
- Second, firms will adjust their demands for traditional inputs (factors of production) if public sector capital services are either substitutes or complements of these factors in the private sector.

The Model

- The public capital services enter the cost function and not the stock for three reasons:
- First Hulten (1990) suggested that there are significant swings in the intensity with which public capital is used. Roads and highways show variation in the rate of utilization as evidenced by the ratio of vehicle miles traveled to the capital stock of roads.
- Second, public capital is a collective input which sectors share in the economy. Since highways are subject to congestion, the amount of public capital that each sector may employ will be less than the total amount supplied.
- Third, firms might have some control on the usage of the public stock in existence (Shan, 1992; Fernald, 1992). For example a firm may have no influence on the level of highways provided by the government, but it can vary its usage of existing highways by choosing routes.

The Model

- Using the properties of the cost function, and differentiating cost with respect to the prices it is possible to obtain the input demands: $(\partial C_{it})/(\partial wxit) = X_{it}$.
- Also denote: $\epsilon_{cy} = \frac{(\partial C_{it})}{(\partial Y_{it})}(Y_{it}/C_{it})$, the elasticity of returns to scale, and $\rho_{cy} = 1/\epsilon_{cy}$ is the degree of returns to scale.
- Also $\phi_{it} = -((\partial C_{it})/\partial t)(1/C_{it}))$ is the input based rate of technological change, and $s_{xit} = (w_{xit}X_{it})/C_{it}$ is the cost share of the X input.
- Finally denote $b_G = -(\partial C_{it})/(\partial G_{it})$ the benefit of highway services in terms of cost reduction.

The Model

- The cost function is also defined as:

$$C_{it} = \sum\nolimits_{x=L,K} w_{xit} X_{it} \tag{4}$$

Where w and X refer to prices and quantities of the private inputs. Total differentiation of this function and division with respect to C yields:

$$\hat{C}_{it} = \sum\nolimits_{x=L.k} \frac{(w_{xit} X_{it})}{C_{it}} \hat{X}_{it} + \sum\nolimits_{x=L.k} \frac{(w_{xit} X_{it})}{C_{it}} \hat{w}_{xit} \tag{5}$$

The Model

- Combining (3) and (5), multiplying both sides by (-1), adding $\hat{Y}_{it}$ in both sides, and assuming that firms within a state minimize costs then our model for total factor productivity growth, $\hat{P}_{it}$, for each state i at time t becomes:

$$\hat{P}_{it} = (1 - \rho_{cy}^{-1})\hat{Y}_{it} - b(G_{it})\hat{G}_{it} - \phi_{it} \quad (6)$$

, where $b(G_{it})$ is the cost elasticity of highway capital services (effect of highway capital services on productivity growth, which is negative) which is an unknown function of the level of highway capital services to be estimated.

The Model

- Congestion effects might imply additional nonlinearities in the unknown function to be estimated.
- Spillover effects might enhance the services from highway capital, but at the same time might increase the congestion faced by each state due to increase of intensity of usage.
- It is assumed that the services of highway capital of state i depend on the highway capital stock of neighboring states, along with the own capital stock and the number of users of state (congestion, $\hat{N}_{it}$) i then:

$$G_{it} = G(H_{it}, \sum_{j} w_{ij} H_{jt}, N_{it})$$

, where $w_{ii} = 1$, for own state, $w_{ij} = 1$ for boarder state and 0 otherwise $(i \neq j)$.

The Model

- Based on the above, and using $S_{it} = \sum_j w_{ij} H_{jt}$ we obtain our general specification:

$$\begin{aligned} \hat{P}_{it} &= \hat{A}_{it} + \lambda \hat{Q}_{it} + \gamma(H_{it}, N_{it}, S_{it})\hat{H}_{it} + \theta(H_{it}, N_{it}, S_{it})\hat{N}_{it} \\ &\quad + \zeta(H_{it}, N_{it}, S_{it})\hat{S}_{it} \end{aligned} \tag{7}$$

The Model

- The marginal benefits of public capital services, G_{it}, are measures of the implicit willingness of the private sector to pay for the services of the public sector capitals calculated as the magnitude of cost reductions experienced by an individual firm as a result of increase in public sector highway capital services.
- The "social" Rate of return is calculated by adding the marginal benefits of each type of public capital services to various firms and dividing by the cost of obtaining one additional unit of publicly financed capital

$$r_H = \{\gamma(.)\frac{C_{it}}{H_{it}} + \sum_j \zeta(.)\frac{C_{it}}{S_{it}} w_{ij}\} / q_{Iit}$$

where q_{Iit} is the marginal cost of publicly financed capital which is assumed to be equal to the deflator for highway investment.

The Model

- We also consider three other specifications:

$$\hat{P}_{it} = \hat{A}_{it} + \lambda \hat{Y}_{it} + \gamma(H_{it})\hat{H}_{it}$$

$$\hat{P}_{it} = \hat{A}_{it} + \lambda \hat{Y}_{it} + \gamma(H_{it}, N_{it})\hat{H}_{it} + \theta(H_{it}, N_{it})\hat{N}_{it}$$

$$\hat{P}_{it} = \hat{A}_{it} + \lambda \hat{Y}_{it} + \gamma \hat{H}_{it} + \theta(N_{it})\hat{N}_{it}$$

The first captures networking effects, the second captures networking and generalized congestion effects and the third congestion effects. They all yield similar results.

Econometric Specification: Estimation

- The above specification is estimated using the semiparametric smooth coefficient model (Fan, 1992; Fan and Zhand, 1999; Li et al, 2002).
- This model imposes no assumption on the functional form of the coefficients. Is linear in the regressors but the coefficients are allowed to vary smoothly with the value of other variables.
- One way of estimating the coefficient functions is by using a local least squares method with a kernel weighting function. A general semiparametric smooth coefficient model is given by:

$$y_i = \alpha(z_i) + x_i' \beta(z_i) + u_i$$

where y_i denotes the dependent variable, x_i denotes a $p \times 1$ vector of variables of interest , z_i denotes a $q \times 1$ vector of other exogenous variables and $\beta(z_i)$ is a vector of unspecified smooth functions of z_i.

Econometric Specification: Estimation

- Equation above can be rewritten as:

$$y_i = X_i^T \delta(z_i) + \varepsilon_i$$

where $\delta(z_i) = (\alpha(z_i), \beta(z_i)^T)^T$ is a smooth but unknown function of z. One can estimate $\delta(z)$ using a local least squares approach, where

$$\begin{aligned} \widehat{\delta}(z) &= \left[(nh^q)^{-1} \sum_{j=1}^{n} X_j X_j^T K\left(\frac{z_j - z}{h}\right) \right]^{-1} \\ &\times \left[(nh^q)^{-1} \sum_{j=1}^{n} X_j y_j K\left(\frac{z_j - z}{h}\right) \right] \end{aligned}$$

$K(.)$ is a kernel function and $h = h_n$ is the smoothing parameter for sample size n.

Econometric Specification: Estimation

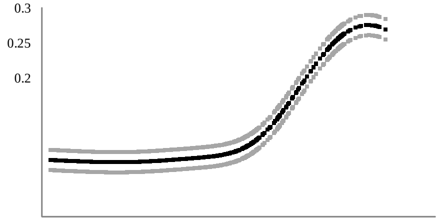
- Under the conditions that $h \to 0$ and $nh^q \to \infty$, one can show that the local least squares regression of y_j on X_j provides a consistent estimate of $\delta(z)$. In general it can be shown that

$$\sqrt{nh^q}(\widehat{\delta}(z) - \delta(z)) \to N(0, \Omega)$$

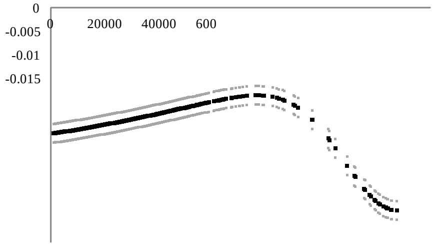
where Ω can be consistently estimated. The estimate of Ω can be used to construct confidence bands for $\widehat{\delta}(z)$.

Econometric Specification: Estimation

- We use the standard multivariate kernel estimator with Gaussian kernel and cross validation to obtain the bandwidth. In the specification state and time dummies are included to capture specific technological shocks and business cycle effects
- We discuss the results from the general model specification, which were obtained using graphical tools. For the graphical analysis one needs to hold the two out of the three variables in the unknown functions at the mean otherwise a multidimensional graph is needed. Changing the means one can also establish cross effects (95% confidence intervals are also included).
- First, for the parametric part of the specification the scale effect was found to be: $(\lambda = -0.00204, se = 0.0018, \rho_{cy}^{-1} = 1.002)$. The F-tests performed indicate that the dummies are jointly significant and therefore should be included in all specifications. Also a test provided by Fan and Li (1996), suggested that our smooth semiparametric specification could not be rejected in favor of a more general nonparametric specification (the p-value of the test is 0.508).

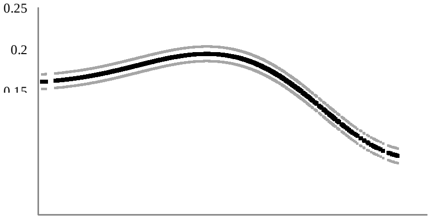


Highway Capital effect on Productivity



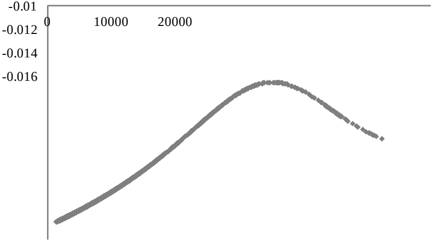
Congestion effect on productivity

Results: Effects on Productivity

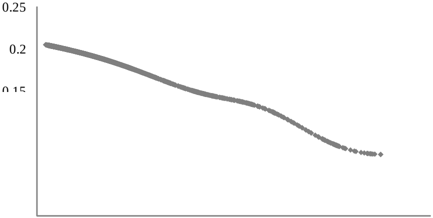


Spillover effect on productivity

Results: Cross Effects

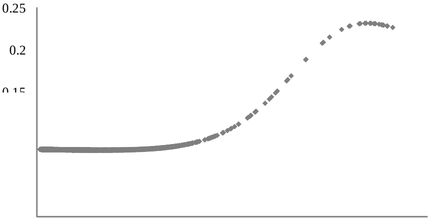


Congestion effect w.r.t. highway capital

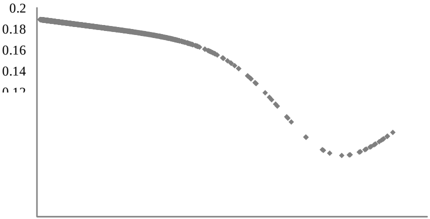


Spillover effect w.r.t. highway capital

Results:Cross Effects

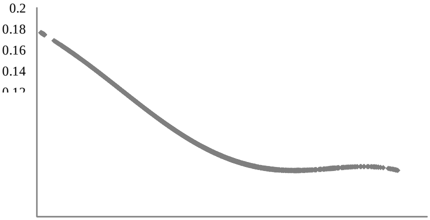


Highway effect w.r.t. congestion

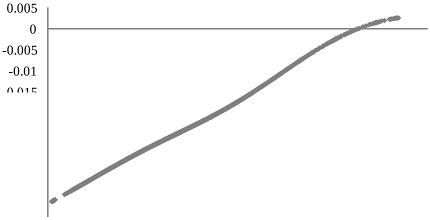


Spillover effect w.r.t. congestion

Results:Cross Effects



Highway effect w.r.t. spillovers



Congestion effect w.r.t. spillovers

"Social" Rates of Return per state

Table 2: Mean Rate of return per state- %

	r_H		r_H		r_H
Alabama	22.072	Maine	18.793	Ohio	29.027
Arizona	19.435	Maryland	24.626	Oklahoma	25.976
Arkansas	21.483	Massachusetts	37.543	Oregon	28.736
California	81.095	Michigan	34.602	Pennsylvania	34.501
Colorado	27.994	Minnesota	18.552	Rhode Island	26.167
Connecticut	26.601	Mississippi	16.294	South Carolina	26.256
Delaware	15.883	Missouri	26.396	South Dakota	9.1271
Florida	20.398	Montana	10.704	Tennessee	19.951
Georgia	23.943	Nebraska	16.318	Texas	37.993
Idaho	15.361	Nevada	18.069	Utah	15.303
Illinois	34.171	New Hampshire	16.632	Vermont	12.087
Indiana	31.283	New Jersey	35.175	Virginia	22.918
Iowa	16.891	New Mexico	16.385	Washington	20.441
Kansas	18.883	New York	68.078	West Virginia	17.951
Kentucky	16.509	North Carolina	28.329	Wisconsin	23.964

Summary of Results: Highway

- Controlling for state and time effects, semiparametric TFP growth estimation shows that highway capital has significant positive effect on state productivity (via cost reductions)
- The effect however is not constant. It varies (from 0.07 to 0.28) and as highway capital increases its effect declines (diminishing effect)
- Initial investment have positive but rather stable benefits. As investment in highway capital increases this yields high benefits, but in high levels the effect of subsequent investment diminishes. Therefore, opportunities for high productive investment diminishes in high levels of highway capital capturing the networking effect.

Summary of Results: Highway

- The average highway capital effect increases as congestion increases but up to a point. After a certain threshold, more vehicles in a road reduce its productivity since they reduce the services of highway capital.
- The average highway capital effect decreases as spillovers increases and after a point the effect remains stable. Spillovers hamper the highway capital contribution.
- Using the elasticities of highway capital and spillovers, its "social" rate of return is constructed, which also includes congestion. These rates range from 9% to 81% and when plotted we observe that it diminishes throughout the years in all states (further support to the networking effect). Also, on average, the rate is higher for states with higher highway capital stocks, and higher highway elasticities.

Summary of Results: Congestion

- Congestion has a negative, heterogeneous effect on productivity. More vehicles in a highway reduce state productivity.
- The average congestion effect declines as highway capital increases. More roads reduce congestion but up to a point (after that marginal increases will have no effect on congestion).
- The average congestion elasticity increases as spillovers increases. As spillovers increase so does the congestion effect faced by each state due to increase of intensity of usage.

Summary of Results: Spillovers

- Spillovers also have a positive, heterogeneous effect on productivity. *They also seem to have a higher effect than own highway capital stock. The explanation may be that others have the benefits and not the cost of highway capital (this effect can be considered as a net effect since only the residents of a state pay taxes for their highways. So people from near states can use the highway but they do not pay taxes).* The effect also diminishes as spillovers increase.
- Spillovers are also subject to congestion and networking effects
- The average effect of spillovers decrease as highway capital increases (substitutes). More and better highways cause the effect of spillovers to decrease.
- The average elasticity of spillovers decreases as congestion increases. Specifically, in low levels of congestion, there is a rather stable, decreasing effect of spillovers. As the number of vehicles increases (in high levels of congestion), we observe an increase in the average effect (maybe people are looking for alternative ways to travel, like a neighboring network)

Conclusions

- The services of highway capital appear to be subject to networking effects and therefore its elasticity (and rate of return) will depend on the level of highway capital stock
- Linear regression estimates will understate the effect of highway capital in states in which highway capital is low, while it will overstate its effect in states in which highway capital is high
- Highway capital is subject to congestion and spillovers effects, which contribute more to the non-linear effect of highway capital. The average effect of highway increases with congestion but up to a point, and decreases with spillovers.

Conclusions

- Highway capital has a significant positive effect on state productivity, an effect that varies across states and time. Its "social" rate of return diminishes over time in all states.
- All these aspects of highway capital, should be taken into consideration in the US before any new investment take place. Governments should not rush to increase highway capital without careful examination, since its marginal benefit of the past might not be a good indicator of its marginal benefit of today.

The End

Thank You