# On the Productive Effects of Public Capital Maintenance: Evidence from U.S. States

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August 2011

**Abstract**

This paper assesses the productivity effects of infrastructure's operations and maintenance (O&M) spending by state and local governments in the 48 contiguous U.S. states over the period 1978-2000. We explicitly account for transboundary spillovers and follow a semiparametric methodology that allows us to estimate state-specific output elasticities. We find strong evidence that in all 48 states the cross-state spillover effects of O&M outlays on productivity exceed their within-state impacts and that they are substantially higher than the spillover effects of capital expenditures. These results are robust to a number of sensitivity tests, including the potential endogeneity of public spending.

**JEL classification:** C14, E22, E62, H76, O11, O47, R11.
**Keywords:** total factor productivity growth, infrastructure, operations and maintenance expenditures, spillovers, semiparametric estimation.

**Acknowledgements:** We are grateful to T. Stengos for sharing with us his Gauss routines and for many constructive discussions. The code for local GMM estimation was generously provided by M. Delis. We have also benefited from comments and suggestions by J. Caballé, E. Dinopoulos, L. Gambetti, S. Gnocchi, E. Ketteni, N. Musick, V. Sarantides, A. Zervou, and seminar participants at the Royal Economic Society 2011 Conference, the 8th Conference on Research on Economic Theory & Econometrics, the Athens University of Economics and Business, and Universitat Autònoma de Barcelona. Financial support under the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II, co-financed by the European Union (European Social Fund – ESF) and Greek national funds, is gratefully acknowledged. The usual disclaimer applies.

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# 1 Introduction

The productive effect of government capital has attracted a lot of research over the past two decades and a large part of the literature has specifically focused on the role of public infrastructure investment in the U.S. economy.[1] Early literature (e.g. Aschauer, 1989; Munnell, 1990a,b) found very large returns from public spending on infrastructure implying that a substantial part of the productivity slowdown of the 1970s and 1980s in the U.S. was due to a shortfall of infrastructure investment. Subsequent studies, based on state-level production functions, pointed out a number of econometric issues and changed the picture dramatically by concluding that total public infrastructure has an insignificant impact on output, a finding called '*the public-capital-productivity puzzle*' (Evans and Karras, 1994; Holtz-Eakin, 1994; Baltagi and Pinnoi, 1995; Garcia-Millà et al., 1996). In turn, a strand of research has investigated the extent to which state infrastructure provides productivity benefits beyond the narrow confines of each state's borders (Holtz-Eakin and Schwartz, 1995; Boarnet, 1998; Boisso et al., 2000; Cohen and Paul, 2004; Pereira and Andraz, 2008; Sloboda and Yao, 2008). A state's output can be positively affected by other states' public infrastructure when benefits are diffused, for instance, through manufacturer-supplier networks, reduction of travel time and logistics costs.[2]

Even though the literature on the U.S. public infrastructure - productivity nexus is extensive, it has not accounted for operations and maintenance (O&M) spending, defined as expenditures '*generally required to provide the services needed for infrastructure to function and that are often necessary for the repair and safe operation of existing infrastructure*' (Congressional Budget Office, 2007). The nation-wide figures provided recently by the Congressional Budget Office report show that the share of O&M expenditures in total public spending on transportation and water infrastructure has averaged around 49% over the period 1956-2004.[3] State and local governments (SLGs) account for the vast majority (close to 90%) of O&M expenditures with the relative share in

[1] See Gramlich (1994), Sturm et al. (1998), and Romp and de Haan (2007) for extensive literature surveys.

[2] Hulten and Schwab (1997, p.157) offer some typical examples: '*...an interstate highway in Illinois does offer some benefits to the residents of other states, a sewage treatment plant in Maryland that reduces water pollution in the Chesapeake Bay benefits people in a wide region*'. Note that the possibility of public capital having negative spillovers at local geographies because economic activity may be drawn to the locale with the infrastructure investment and away from otherwise equivalent areas has also been theorized in the literature (see Boarnet, 1998).

[3] Transportation and water infrastructure has been typically considered in the public-capital-productivity literature following Munnell (1990b), with the main analyzed components including highways and streets, water and sewer facilities, and other buildings and structures.

their total infrastructure expenditures rising steadily from 41% in 1956 to 63% in 2004. Moreover, since the late 1970's real infrastructure spending by SLGs has been growing at a faster annual rate than corresponding federal outlays and has accounted for about 75% of total public-sector spending on infrastructure. These stylized facts provide strong motivation for an empirical assessment of the productivity impact of O&M outlays by SLGs in addition to the widely-explored traditional effect of capital spending.

The aim of the present study is to explore empirically the direct and spillover effects of O&M spending on total factor productivity (TFP) growth among the 48 contiguous U.S. states. We use a new state-level dataset for capital and O&M spending on water and transportation infrastructure, which we have assembled for the period 1978-2000 based on the Census Bureau's SLG Finances series. Its budgetary nature stands in contrast to the approach typically followed in the literature, which has mainly used (often controversial) estimates of public capital stocks, and allows us to pursue a topic left unexplored in previous studies, namely the assessment of the productivity impacts of O&M outlays and their comparison with the corresponding ones for capital spending.

To this end, we adopt an econometric methodology that employs a semiparametric varying-coefficient specification. The main advantage of our empirical approach is that it offers observation-specific estimates of output elasticities, following recent developments in the literature that have emphasized the importance of parameter heterogeneity and nonlinearities in the growth process (see e.g. Masanjah and Papageorgiou, 2004; Henderson et al., 2010). Our empirical findings indicate, first, that interstate spillovers are significantly positive and exceed within-state impacts for O&M (and capital) spending, implying that there is a substantial wedge between the aggregate and the own-state rates of return. Second, the spillover effect of O&M spending is found to be on average up to eight times higher than the corresponding impact of capital spending. These findings remain robust to a battery of sensitivity tests, including the potential endogeneity of public spending and the measurement of the spillover variables.

The approach adopted here is thus close in spirit to Henderson and Kumbhakar (2006), who have attributed the *'public-capital-productivity puzzle'* to neglected nonlinearities in the production process and have recovered via a nonparametric approach statistically significant returns to public capital, yet without considering any spillover effects of public spending.[4] Notably, there is only scant

[4] Earlier results by Fernald (1999) also underscored the existence of nonlinearities in the production function. In a

evidence on the productive impact of public spending on capital maintenance. Kalaitzidakis and Kalyvitis (2005) have used nation-wide data from the Canadian 'Capital and Repair Expenditures' survey and have found that Canada would benefit from a fall in total expenditures on both public capital and maintenance and that the aggregate share of maintenance in total expenditures should be lower. Other studies examining the role of O&M spending (e.g. Tanzi and Davoodi, 1997; Ghosh and Gregoriou, 2008) have confirmed that capital maintenance is an important determinant of growth, but have used only proxies due to the lack of reliable and consistent data.[5] In all these studies the spillover effects of public capital maintenance are not taken into account. The present paper contributes to the literature by using spending data on public capital maintenance by SLGs and highlighting the inter-regional productivity spillovers of O&M outlays among U.S. states, in comparison to standard capital outlays employed in related literature.

We close the introductory section by noting that the existence of large spillover benefits of local O&M spending to users in other states provides a strong rationale for public spending on O&M by SLGs, despite its relatively small, and mostly negative, within-state impacts. In this vein, some federal coordination of states' policies might be necessary to ensure that O&M expenditures at the state and local level are not suboptimally provided, as SLGs might be 'too small to think big enough' creating a collective action problem. Given the central importance of infrastructure spending in fiscal stimulus packages, like the American Recovery and Reinvestment Act of 2009, these results seem therefore to have important policy implications.

The rest of the paper is organised as follows. Section 2 outlines the empirical methodology, Section 3 describes the data and Section 4 presents the estimation results. Section 5 performs a sensitivity analysis and, finally, Section 6 concludes the paper.

similar vein, Aschauer (1999) found that, whereby linear estimates of production functions deliver an infrastructure effect that disappears when state effects are introduced, allowing for nonlinearity delivers a robust effect of public capital on economic growth. In addition, Duggal et al. (1999) specified a technological growth rate as a nonlinear function of infrastructure and demonstrated that the impact of infrastructure on the U.S. economy is not constant. More recently, Égert et al. (2009) use thresholds models in a Bayesian-averaging framework and find that the impact of infrastructure investment on growth is highly nonlinear, varying across OECD countries and over time. Similarly, Colletaz and Hurlin (2006) have used a Panel-Smooth-Threshold model and find strong threshold effects in the relationship between output and public capital.

[5]Some evidence on theproductivity impact of public capital maintenance in the U.S. comes from case studies or cost-benefit analyses concentrated in highways. An exception is Pinnoi (1994) who provided production function estimates suggesting that state and local expenditures for highway maintenance are productive with respect to the private and non-agricultural non-manufacturing (NANM) sectors, but counterproductive in the agricultural and manufacturing sectors. See Section 5 for more details on studies with data for highways.

## 2 Empirical methodology

Our empirical setup relies on Barro's (1990) seminal paper, which introduced in theoretical models government spending as an input to the production process. Devarajan et al. (1996) further specified two types of government spending -one more productive than the other- as production inputs and, in a similar spirit, Pinnoi (1994) seperated in his empirical study the effect of services from highways and streets in the production function into capital and maintenance outlays.

In this context, we begin by assuming a general production function with two types of government spending as inputs, namely capital and O&M expenditures on public infrastructure:

$$Y = F\left(K,\ L,\ g_c,\ g_{om},\ S_c,\ S_{om},\ t\right) \tag{1}$$

where $Y$, $K$ and $L$ represent the amounts of total output, private capital and labour respectively, $g_c$ and $g_{om}$ denote *own-state* public spending for infrastructure capital and O&M, while $S_c$ and $S_{om}$ represent a weighted sum of *other states'* capital and O&M spending, and hence form transboundary spillover indices.[6] Finally, $t$ is a time trend generally interpreted in this literature as an exogenous technology index.

Equation (1) implies that both capital and O&M spending on public infrastructure should be conducive for a state's output production. While the rationale regarding the capital component is straightforward since capital expenditures add directly new capacity to the existing infrastructure stock, the channel through which O&M expenditures contribute to private production deserves some comment. Rioja (2003), Kalaitzidakis and Kalyvitis (2004), and Dioikitopoulos and Kalyvitis (2008) have developed models that investigate the positive externalities of maintenance expenditures arising through endogenous public capital depreciation and the associated implications for growth. Hence, maintenance spending is expected to have an indirect positive influence on the accumulation of public infrastructure through countering depreciation.[7]

[6] See next section for a detailed description of the spillover indices. Cohen and Paul (2004) include a similar spatial-spillover index of highway stocks as an input to a cost function, noting that this adaptation is similar to models allowing for agglomeration effects (e.g. Bartlesman et al., 1994). Holtz-Eakin and Schwartz (1995) have added a term of neighboring states' highway stock to a standard production-function model, while Sloboda and Yao (2008) include spillover variables of public spending in their estimated production function. In a different context, the literature that views innovation efforts as a major source of technological progress has extensively studied international R&D spillovers, i.e. the extent to which a country's TFP depends not only on domestic R&D capital but also on foreign R&D capital (see e.g. the seminal paper of Coe and Helpman, 1995).

[7] One may further argue that O&M spending also affects the service flow of the existing infrastructure stock and in

Differentiating equation (1) with respect to time, dividing by $Y$, and rearranging terms yields below a standard growth-accounting framework for our analysis:

$$\overset{\wedge}{Y} - \varepsilon_{Y,K}\overset{\wedge}{K} - \varepsilon_{Y,L}\overset{\wedge}{L} = \overset{\wedge}{A} + \varepsilon_{Y,g_c}\overset{\wedge}{g}_c + \varepsilon_{Y,g_{om}}\overset{\wedge}{g}_{om} + \varepsilon_{Y,S_c}\overset{\wedge}{S}_c + \varepsilon_{Y,S_{om}}\overset{\wedge}{S}_{om} \tag{2}$$

where $(\wedge)$ above a variable denotes its growth rate, $\varepsilon_{Y,Q} = (\vartheta \ln Y)/(\vartheta \ln Q)$ for $Q = K$, $L$, $g_c$, $g_{om}$, $S_c$, $S_{om}$ denotes the corresponding output elasticity, and $\overset{\wedge}{A} \equiv (\vartheta F/\vartheta t)/Y$ is the exogenous rate of technological progress.

Next, we define a Törnqvist index of TFP growth, based on the private factors, to discretely approximate the left-hand side of equation (2). Assuming a perfectly competitive environment, the output elasticities of capital and labour should equal the observed income shares, $S_{YK}$ and $S_{YL}$ respectively, so that the Törnqvist TFP-growth index is defined for state $i = 1, ..., N$ in year $t = 1, ..., T$ as follows:

$$T\overset{\wedge}{F}P_{it} \equiv \Delta \ln Y_{it} - \bar{S}_{YK,it}\Delta \ln K_{it} - \bar{S}_{YL,it}\Delta \ln L_{it} \tag{3}$$

where $\bar{S}_{YK,it} \equiv 0.5\,(S_{YK,it} + S_{YK,it-1})$ and $\bar{S}_{YL,it} \equiv 0.5\,(S_{YL,it} + S_{YL,it-1})$. The above expression shows that the contribution of each private input is allowed to differ both intra- and inter-temporally and can be directly observed from the data. This index measures technological change if the production function contains only the traditional inputs, $K$ and $L$ (see Diewert, 1976). In our model we include government capital and O&M spending as additional production inputs, which implies that equation (3) represents a biased index of technological change that will be affected by changes in $\overset{\wedge}{g}_c$, $\overset{\wedge}{g}_{om}$, $\overset{\wedge}{S}_c$ and $\overset{\wedge}{S}_{om}$.

In the right-hand side of equation (2), the unobserved contributions of capital and O&M expenditures to aggregate production, both at the intra- and inter-state levels, are modelled as unknown functions of the O&M share in total infrastructure spending ('O&M share' henceforth), i.e. $\varepsilon_{Y,g_c} = \theta_1\left(\frac{g_{om}}{g_c+g_{om}}\right)$, $\varepsilon_{Y,g_{om}} = \theta_2\left(\frac{g_{om}}{g_c+g_{om}}\right)$, $\varepsilon_{Y,S_c} = \theta_3\left(\frac{g_{om}}{g_c+g_{om}}\right)$, and $\varepsilon_{Y,S_{om}} = \theta_4\left(\frac{g_{om}}{g_c+g_{om}}\right)$, to account for the potential impact of the relative size of the two public spending components on the

a production function should be multiplied with the service flow of the existing infrastructure stock to get an effective service flow (in the same way that electricity expenditures can be entered multiplicatively with capital to proxy for utilization). However such a specification would require the construction of public capital stocks that so far in the literature assumes constant depreciation rates, i.e. unrelated to maintenance spending.

estimated output elasticities. Kalaitzidakis and Kalyvitis (2004, 2005) have shown that the relationship between growth and the composition of infrastructure spending is expected to be nonlinear, since one unit of capital spending adds *directly* to the public infrastructure stock, whereas the same amount of maintenance expenditures has an *indirect* impact through the depreciation rate. The 'O&M share' is therefore treated as a source of potential response heterogeneity since capital and O&M expenditures are imperfect substitutes in the accumulation of the public infrastructure stock.

Combining the above, equation (2) can be written as follows:

$$\overset{\wedge}{TFP}_{it} = \overset{\wedge}{A}_{it} + \theta_1 (Z_{it}) \overset{\wedge}{g}_{c,it} + \theta_2 (Z_{it}) \overset{\wedge}{g}_{om,it} + \theta_3 (Z_{it}) \overset{\wedge}{S}_{c,it} + \theta_4 (Z_{it}) \overset{\wedge}{S}_{om,it} \tag{4}$$

where $Z \equiv \frac{g_{om}}{g_c + g_{om}}$. Equation (4) allows the growth of both own-state and other states' spending for infrastructure capital and O&M to influence TFP growth nonlinearly by introducing heterogeneity in the marginal effects.[8]

To proceed with the estimation, we model the exogenous rate of technological progress, $\overset{\wedge}{A}_{it}$, as a function of state-specific dummy variables, $D_i$, capturing idiosyncratic exogenous technological change, and a time trend, $t$, capturing any time-related exogenous shifts in technology. The empirical counterpart of equation (4) is thus given by:

$$\begin{aligned} \overset{\wedge}{TFP}_{it} &= \underbrace{\alpha_0 + \sum_{i=1}^{N-1} \alpha_i D_i + bt}_{linear\ part} + \theta_1 (Z_{it}) \overset{\wedge}{g}_{c,it} + \theta_2 (Z_{it}) \overset{\wedge}{g}_{om,it} + \theta_3 (Z_{it}) \overset{\wedge}{S}_{c,it} + \theta_4 (Z_{it}) \overset{\wedge}{S}_{om,it} + u_{it} \\ &\equiv W_{it}' \alpha + X_{it}' \beta (Z_{it}) + u_{it} \end{aligned} \tag{5}$$

where $\alpha_0$ denotes an intercept, $W_{it} \equiv (1, D_i, t)'$, $\alpha \equiv (\alpha_0, \alpha_i, b)'$, $X_{it}' \equiv \left( \overset{\wedge}{g}_{c,it}, \overset{\wedge}{g}_{om,it}, \overset{\wedge}{S}_{c,it}, \overset{\wedge}{S}_{om,it} \right)$, $\beta (Z_{it}) \equiv (\theta_1 (Z_{it}), \theta_2 (Z_{it}), \theta_3 (Z_{it}), \theta_4 (Z_{it}))'$, and $u_{it}$ is the error term that satisfies $E (u_{it} \mid W_{it}, X_{it}, Z_{it}) = 0$. Equation (5) is the centerpiece of our empirical analysis that accounts for the intrastate and the transboundary spillover effects of capital and O&M spending on TFP growth.

[8] Notice that defining TFP based on the private factors (the well-known Solow residual) and relating it to government services, which dates back to Aschauer (1989) and Hulten and Schwab (1991), allows us here to obtain a more parsimonious -in terms of number of parameters- specification than in the case of the corresponding production function. Cost-function specifications have also been used in the literature, offering the advantage of explicitly taking into account possible endogeneity of inputs, but in a limited number of studies, since historical price data is typically available only for manufacturing firms.

Due to the presence of the linear part, $W'_{it}\alpha$, equation (5) forms a *partially linear* varying-coefficient specification. The estimation approach we follow is based on the semiparametric smooth-coefficient model proposed by Li et al. (2002) as a flexible specification for studying a general regression relationship with varying coefficients (see e.g. Fan and Zhang, 1999; Cai et al., 2000a,b). The smooth-coefficient model lets the marginal effect of the variable of interest to be an unknown function of an observable covariate and hence introduces heterogeneity into the marginal effect. This semiparametric specification traces nonlinearities in the estimated relationships, offering the advantage of more flexibility in functional form than parametric counterparts, as the smooth-coefficient functions are unspecified. Furthermore, by allowing coefficients to depend on other variables it does not suffer the 'curse of dimensionality' problem to the extent of a purely nonparametric specification. Additionally, the sample size required to obtain a reliable semiparametric estimation is not as large as in the case of a nonparametric model. To estimate equation (5) we follow a three-step process described in detail in the Companion Appendix to the paper (see also Chou et al., 2004).

## 3 Data

Our sample covers the 48 contiguous U.S. states over the period 1978-2000 with a total of 1104 observations.[9] A brief description of the data (measured in millions of 2000 U.S. dollars) follows; further details about data sources and the method of construction of all the variables used in the estimations are provided in the Data Appendix.

We obtain data on SLG expenditures from the 'Rex-Dac' database, which is an internal file of the U.S. Census Bureau. This database is an archive of nearly all the data collected in the periodic censuses of governments and annual surveys of government finances since 1977 (plus 1972).[10] Following the classification by Congressional Budget Office (2007), for O&M and capital expenditures on water and transportation infrastructure, $g_{om}$ and $g_c$, we consider data on 'current operations' and 'capital outlay' respectively, on the five following functions: aviation, highways and roads, mass transit, water supply and wastewater treatment, and water transportation, which also cover

[9] In line with the literature Alaska, Hawaii, and the District of Columbia are excluded from the sample.

[10] The database, with 1,300 finance items spread across eight data tables, is available (in Microsoft Access 2000 format) at http://www2.census.gov/pub/outgoing/govs/special60/. Data become available annually from 1977 onwards, while there are no state-level statictics available for local governments (i.e. counties, municipalities, townships, special districts and school districts) in 2001 and 2003, because for the corresponding finance surveys the sample was redesigned to provide only national estimates. This restricts our sample to the period 1978-2000.

the core sectors of public infrastructure routinely used in related literature. 'Current operations' comprises direct expenditure for compensation of own officers/employees and for supplies, materials, and contractual services except any amounts for capital outlay. It also includes repair and maintenance services to maintain required standards of compliance for the intended use. 'Capital outlays', on the other hand, are costs associated with: (i) construction, i.e. production, additions, replacements, or major structural alterations to fixed works, by contract or government employee (ii) purchase of land, existing structures, and equipment. Capital expenditures include purchases of new assets as well as major improvements/alterations to existing assets.[11]

Spillover variables, $S_c$ and $S_{om}$, for each state are constructed as a weighted sum of infrastructure capital and O&M spending in other states. Different states are weighted, first, by commodity flows across states to reflect different degrees of interstate dependence and, second, with information on the relative sizes of state-level economic activity.[12] This weighting scheme is justified by the fact that a state with a high level of economic activity, such as New York, presumably constitutes large portions of $S_c$ and $S_{om}$ for a relatively small state, such as Rhode Island. Thus, by multiplying New York's infrastructure spending by the ratio of Rhode Island's gdp to its own gdp, which is a relatively small number, the size effects in the construction of $S_c$ and $S_{om}$ for Rhode Island are neutralized. The above weighting strategy aims at capturing the different degrees of economic ties and geographic connections between states by avoiding the oversimplifying assumption that each dollar spent by other states has equal interregional spillover effects on any targeted state.

Finally, to construct the state-by-year TFP index we use data on output, capital and labor for the private non-farm sector. Output, $Y$, is defined as the real GDP, and labor, $L$, is defined as the total number of workers. Estimates of state-level capital stocks, $K$, are from Garofalo and Yamarik (2002).

[11] For a detailed description of what exactly constitutes our two main spending categories, see U.S. Census Bureau, 'Government Finance and Employment Classification Manual, Chart 8-A: Description of Character and Object Categories' (source: http://www.census.gov/govs/www/class_ch8_charta.html). For a definition of each type of infrastructure, see 'Appendix B, Web Supplement to Trends in Public Spending on Transportation and Water Infrastructure 1956 to 2004' (source: http://www.cbo.gov/ftpdocs/85xx/doc8517/WebAppendix.pdf).

[12] Because no corresponding time series is available for the commodity-flows data, we use an average of the data for 1993 and 1997, which also eliminates potential endogeneity concerns. This approach was first used by Cohen and Paul (2004) to approximate network effects of highway infrastructure and was subsequently followed in part by Sloboda and Yao (2008) to treat different degrees of interstate dependence. We test below the sensitivity of our results to the usage of these weights by employing an alternative computation of the spillover variables, which maintains in the weighting procedure only the information on the relative economic activity. Further, we show that our results hold in a sample of highway data since this weighting scheme was first applied in the case of highways.

Table A1 presents data averages by state for the TFP-growth index (our dependent variable) and for the regressors used in the estimations. TFP on average increased over the 1978-2000 period in all states. Connecticut and Massachusetts experienced the largest productivity-growth rates of about 1.8% and 1.7% respectively, while, on the opposite side, the productivity-growth rate for Montana was close to zero. Between 1978 and 2000 capital spending grew positively in most states at a mean rate of 1.8%. For nine states (IL, LA, ME, MD, MT, NH, ND, VT, and WV) the average growth rates in capital expenditures were negative. In contrast, O&M spending grew positively in all states at a mean rate of around 2.9%. Table A1 also reports the average level of the 'O&M share'. This ranges from 35.7% (WY) to 65% (MI) with the majority of U.S. states (28 in number) exhibiting figures above 50%. Overall, the summary statistics for our data show considerable variability across states.

## 4 Estimation results

In this section, we present our empirical findings for the semiparametric model outlined in Section 2. Our focus is placed on the estimated output elasticities with respect to own-state capital and O&M outlays as well as capital and O&M outlays by other states. As has been shown in Section 2, these elasticities correspond to the coefficient functions $\theta_1(.)$, $\theta_2(.)$, $\theta_3(.)$ and $\theta_4(.)$, respectively.

As a benchmark, we initially estimate the model treating the $\theta$'s as constants, i.e. by assuming that the estimated relationships are linear. The first column of Table 1 gives the results from a specification that does not account for spillover effects. As can be readily seen, we obtain statistically insignificant estimates for the output elasticities of both capital and O&M outlays on public infrastructure. This result is in line with the existing literature on the 'public-capital-productivity puzzle' in the U.S., which has stated that once either state or both state and time effects are controlled for, the resulting estimates of the marginal productivity of public capital are not significantly different from zero (see, among others, Holtz-Eakin, 1994; Baltagi and Pinnoi, 1995; Garcia-Milà et al., 1996). In the second column of Table 1, we run a similar linear regression that accounts for spillover effects. We obtain again insignificant estimates for both intrastate effects, whereas the estimates for the corresponding cross-state spillover effects turn out positive and statistically significant.

As pointed out by Henderson and Kumbhakar (2006), neglected nonlinearities are important in assessing the productive impact of public infrastructure. We thus proceed to semiparametric estimation of equation (5) without imposing any restriction on the functional form of the coefficients. The estimated coefficients are observation-specific, meaning that output elasticities with respect to capital and O&M spending are derived for each state and time period. We depict the semiparametric smooth coefficients along with the upper and lower limit of the 95% bootstrap confidence interval in Figure 1. For comparison purposes, we also plot the estimated parameters from the parametric linear specification (depicted by the dashed lines). The effects from the semiparametric regression are estimated conditional upon the 'O&M share' and the graphs clearly suggest that the functions are nonconstant in the range of the state variable, exhibiting nonlinear patterns.[13]

In detail, the upper diagrams of Figure 1 plot pointwise estimates of the output elasticities with respect to states' own capital and O&M outlays, $\theta_1(Z_{it})$ and $\theta_2(Z_{it})$ respectively. Both graphs indicate that the estimated elasticities are positive for a range of medium-to-high (exceeding 50%) levels of the 'O&M share'. The lower diagrams of Figure 1 similarly plot output elasticities with respect to capital and O&M outlays by other states, $\theta_3(Z_{it})$ and $\theta_4(Z_{it})$ respectively, and show that both cross-state spillover effects are positive for all sample points. In addition, the plotted results indicate that $\theta_3(Z_{it})$ and $\theta_4(Z_{it})$ initially decline and then start increasing above a certain level of the 'O&M share', with these convex relationships implying that for low and high levels of the 'O&M share' the productivity spillover effects are relatively higher. Overall, the graphical analysis suggests that for medium levels of the 'O&M share' within-state effects appear positive and cross-state spillover impacts take their lowest values, while for lower/higher levels of the 'O&M share' within-state effects are negative and spillover effects take their highest values. This evidence seems to imply substitutability between own-state infrastructure outlays and other states' outlays.

To examine the effects by state, we calculate the average output elasticities for each state, along with the corresponding standard errors. The results are reported in Table 2, in which states are grouped into broad census regions to allow for a comparative regional analysis.[14] The state-specific

[13] It is worth noting that we have also estimated the model parametrically by specifying the varying coefficients as a second-degree polynomial of $Z_{it}$ (based on the graphs below for $\theta_1(Z_{it})$, $\theta_3(Z_{it})$ and $\theta_4(Z_{it})$). The coefficients on the quadratic terms turned out statistically significant in the case of $\theta_1$, $\theta_3$ and $\theta_4$, with $t$-statistics -1.89, 2.50 and 2.30, respectively, which indicates that the use of the smooth-coefficient semiparametric model is justified.

[14] Semiparametric estimation of the model without the spillover variables resulted in positive, although small, mean effects amounting to 0.006 and 0.009, respectively. The detailed results by state are available in the Companion Appendix to the paper.

estimates indicate that the elasticities of own-state O&M spending lie between -0.027 (NE) and 0.0004 (NY), whereas the corresponding elasticities of capital spending range between -0.022 (WY) and 0.0034 (IN). This picture is summarized in the means of the obervation-specific elasticities, which are statistical significant and amount to -0.017 and -0.002 for O&M and capital expenditures, respectively, implying that, ceteris paribus, a 1% increase in O&M (capital) spending corresponds, on average, to a 0.017% (0.002%) fall in output.[15]

In contrast, the output elasticities of other states' expenditures are much greater in magnitude ranging from 0.37 (MO) to 0.46 (MI) for O&M spending and are always statistically significant. The corresponding effects of capital spending are also positive and statistically significant, but are much lower in magnitude ranging from 0.033 (OH) to 0.095 (WY). Our estimates imply that a 1% increase in O&M (capital) spending by other states corresponds, on average, to a 0.39% (0.046%) increase in output. To illustrate the spatial allocation of the spillover effects, Figure 2 depicts geographically the mean impacts of O&M spending by other states grouped in quartiles. Twelve states (WY, NV, AZ, CA, NM, GA, MI, PA, MD, VT, NH, ME) receive relatively higher spillover effects, while a group of another twelve states (OR, WA, KS, CO, OK, MO, IA, MN, IN, OH, MS, AL) receive relatively low spillover effects.[16]

In sum, two broad conclusions can be drawn from our empirical analysis. First, productivity spillovers of O&M (and capital) outlays by other states are significantly positive and exceed the corresponding impacts of within-state outlays. Second, the spillover effect of O&M spending is found to be on average up to eight times higher than the corresponding impact of capital spending.

# 5 Sensitivity analysis

To assess the robustness of our main findings reported earlier, in this section we perform a battery of sensitivity tests. First, an essential concern might regard the possibility of endogenous variables

[15] Negative estimates for the productivity effect of public capital have been previously reported in the literature (see e.g. Evans and Karras, 1994; Holtz-Eakin and Schwartz, 1995). In addition, Pinnoi (1994) has found negative estimates of ouput elasticities with respect to highway capital outlay and maintenance for some sectors of economic activity and U.S. census regions.

[16] Notice that the state receiving the highest spillover effect of O&M spending (MI) has the highest average 'O&M share' (65.15%) according to Table A1, while the state receiving the highest spillover effect of capital spending (WY) exhibits the lowest average 'O&M share' (35.66%). A detailed presentation of the spatial allocation of the spillover effects of capital spending, as well as the within-state impacts of both O&M and capital spending, are provided in the Companion Appendix to the paper.

in our estimation. For instance, SLGs might endogenously raise capital spending in light of a fall in TFP growth during 'bad' times. We examine this concern by augmenting the analysis with local generalized-method-of-moments (LGMM) regressions, proposed in a dynamic panel-data context by Tran and Tsionas (2010). LGMM can be considered as an extension to the Li et al. (2002) model because it allows for some or all the regressors to be correlated with the error term and for the possibility that the latter is serially correlated.[17] As instruments for our four basic variables we use the kernels of the first two lags of the 'O&M share'.[18] The results, reported in column (2) of Table 3, suggest that the estimates on the direct and spillover effects of capital and O&M spending (average coefficients) are not driven by endogeneity bias. In fact, the coefficient on the spillover impact of O&M spending (equal to 0.5) is higher than in our baseline estimation. Therefore, we feel confident that estimation on the basis of the smooth-coefficient model is robust to potential endogeneity of public spending.

Second, we attempt to control for the influence of other variables that may affect state productivity growth to ensure that our results do not suffer from omitted-variables bias. We therefore include in the linear part of equation (5) the state unemployment rate to account for cyclical effects, as well as the following public-sector variables: 'federal employees' (defined as the log of federal employees per capita), 'S&L employees' (defined as the log of state and local employees per capita), 'federal revenue' (defined as the intergovernmental revenue received by SLGs from the federal government as a share of personal income) and 'tax burden' (defined as total state and local tax revenues as a share of personal income).[19] Additionally, we control for various characteristics of the population by appending our estimated specification with the following variables: 'working population' (defined as the percentage of population between 20 and 64 years of age), 'nonwhite' (defined as the percentage of population that is nonwhite) and 'female' (defined as the percentage of population that is female). The estimation results, reported in column (3) of Table 3, show no

[17] Through including the lagged dependent variable among the regressors, this specification also accounts for the dynamic nature of TFP growth. It is worth noting that we have investigated the possibility of serial correlation in our baseline estimation by regressing the residuals on their first-order lagged values, but the corresponding coefficient did not turn out statistically significant.

[18] Specifically, we use the density-weighted kernel estimates of { $E(T\hat{F}P_{it-1}/Z_{it-1})$, $E(T\hat{F}P_{it-2}/Z_{it-2})$, $E(\hat{g}_{c,it}/Z_{it})$, $E(\hat{g}_{c,it-1}/Z_{it-1})$, $E(\hat{g}_{om,it}/Z_{it})$, $E(\hat{g}_{om,it-1}/Z_{it-1})$, $(\hat{S}_{c,it}/Z_{it})$, $E(\hat{S}_{c,it-1}/Z_{it-1})$, $E(\hat{S}_{om,it}/Z_{it})$, $E(\hat{S}_{om,it-1}/Z_{it-1})$} as instrument for $\{T\hat{F}P_{it-1}, \hat{g}_{c,it}, \hat{g}_{om,it}, \hat{S}_{c,it}, \hat{S}_{om,it}\}$. For more on these issues, see Tran and Tsionas (2010).

[19] See also Reed (2009).

significant change in the average coefficients. Morever, the coefficients on the additional controls generally have the expected signs with those on 'working population', 'federal employees', 'S&L employees', and 'federal revenue' being statistically significant.[20]

Another robustness check is then to use a more general coefficient function that includes a second state variable, namely the share of other states' O&M spending in the sum of the two spillover indices, $\frac{S_{om}}{S_c+S_{om}}$. The average estimation results (average coefficients), presented in column (4) of Table 3, remain practically unchanged. Further, we drop the commodity-flows weights in the computation of the spillover variables and keep only the information on the relative economic activity to investigate whether our results are driven by the use of these weights. Estimation results, reported in column (5) of Table 3, demonstrate that the estimates obtained are again not substantially different from our baseline findings.

Finally, we run the regression for a subsample consisting of highway-spending data. We focus on highways and roads for two reasons. First, they form the largest component of transportation infrastructure, which is believed to make the economy more efficient by reducing the amount of time and energy necessary to cover distances between firms, consumers, and employees. Given their network characteristics, they have so far dominated the literature investigating the spillover-effects question in the context of public infrastructure (e.g. Holtz-Eakin and Schwartz, 1995; Boarnet; 1998; Cohen and Paul, 2004). Second, some cost-benefit studies have emphasized the productive impacts of maintenance expenditures on highways, yet without taking into account their spillover effects.[21] To assess the significance of our results for O&M spending on highways we report in column (6) of Table 3 the estimates obtained by running the regression for highways and streets. Our main findings continue to hold, with the output elasticity of O&M spending by other states

[20] A correlation matrix of the additional controls is available upon request. Data for all public-sector variables are from the Census Bureau's 'Rex-Dac' database, for the state-level unemployment rate they come from the Bureau of Labor Statistics, Local Area Unemployment Statistics (available at http://data.bls.gov/PDQ/outside.jsp?survey=la), and for the population characteristics they come from Pjesky (2006) and can be accessed until 1999 at http://www.econ.canterbury.ac.nz/personal_pages/bob_reed/Papers/index.html. We have also experimented with other control variables, like the size of the population and the degree of expenditure decentralization, but they turned out statistically insignificant. Finally, using the shares of total earnings earned in federal and state and local governments instead of the number of federal and state and local employees produced essentially the same results.

[21] For instance, Congressional Budget Office (1988) has indicated that the return to projects designed to maintain the average condition of the federal highway system could be as high as 30%-40%. In a similar vein, there has been some evidence, based on data from the Federal Highway Administration, suggesting that beyond a certain point maintenance and management of existing infrastructure become more attractive than investment in additional capacity; for instance, road-resurfacing projects have benefit-cost ratios that are nearly double compared with projects that add new lanes (Congressional Budget Office, 1998).

being somewhat lower but still considerably higher than the corresponding effect of capital spending.

## 6 Concluding remarks

Based on a novel set of data for the 48 contiguous U.S. states over the period 1978-2000, this paper aimed at disentangling the productivity impacts of capital and O&M spending on public infrastructure by explicitly accounting for cross-state spillover effects. We used a semiparametric smooth-coefficient approach within a standard growth-accounting framework to simultaneously model nonlinearities and parameter heterogeneity. Our empirical findings documented that interstate spillover impacts are significantly positive and exceed direct impacts for both types of spending. Importantly, the cross-state spillover effect of O&M outlays was estimated to be considerably high. These results were found to be robust to a battery of sensitivity tests including the endogeneity of public spending and alternative measures of the spillover variables.

In answering some questions unresolved up to now this study has opened the door to other important research issues. For instance, this paper has not investigated politico-economic factors that shape infrastructure policy (see e.g. Kemmerling and Stephan, 2002; Cadot et al., 2006). Further work in this area could therefore look into political factors as determinants of state and local infrastructure spending and of its allocation between capital and O&M. Second, 'budget spillovers' have been studied in the literature (see e.g. Case et al., 1993; Baicker, 2005) and the potential for interstate competition to occur in the public infrastructure arena has been pointed out (see e.g. Taylor, 1992). A subsequent question then is whether in the presence of the positive productivity spillover effects found here states respond to increased capital and O&M spending in neighboring states by decreasing their own outlays or engage in expenditure competition to attract new economic activity.

# Data Appendix

*Capital and O&M spending on public infrastructure:* To construct capital spending on water and transportation infrastructure at the state level, we use from the 'Rex-Dac' database the following series: 'Air Trans-Cap Outlay' from Table Rex 2 for aviation, 'Total Highways-Cap Out' from Table Rex 3 for highways and roads, 'Sewerage-Cap Outlay' and 'Water Util-Cap Outlay' from Table Rex 5 for water supply and wastewater treatment, 'Water Trans-Cap Outlay' from Table Rex 5 for water transportation, and 'Transit Util-Cap Outlay' from Table Rex 5 for mass transit. Similarly, to construct O&M spending on water and transportation infrastructure we use the following series: 'Air Trans-Current Oper (E01)', 'Total Highways-Cur Op', 'Sewerage-Current Oper (E80)', 'Water Util-Cur Oper (E91)', 'Water Trans-Cur Oper (E87)', and 'Transit Util-Cur Oper (E94)'. The estimates for $g_c$ and $g_{om}$ are obtained by summing the respective expenditure amounts over the above infrastructure components. Following Congressional Budget Office (2007), both spending series are then deflated by the relevant state and local price index (source: BEA, Table 3.9.4: 'Price Indexes for Government Consumption Expenditures and Gross Investment', http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp?Selected=N#S5).

*Spillovers of capital and O&M spending on public infrastructure:* The measures $S_c$ and $S_{om}$ are respectively computed as a weighted sum of capital and O&M spending on infrastructure in other states:

$$S_{c,it} = \sum_{j \neq i} w_{ij} \cdot g_{c,jt} \cdot \frac{Y_{it}}{Y_{jt}} \text{ and } S_{om,it} = \sum_{j \neq i} w_{ij} \cdot g_{om,jt} \cdot \frac{Y_{it}}{Y_{jt}}$$

where $w_{ij}$ is the weight that each 'other' state $j$ has on state $i$ and $Y$ measures state output. The weight used is defined as the share of the value of goods shipped from state $i$ to state $j$ in the total value of goods shipped from state $i$ to all other states, i.e. $w_{ij} \equiv \alpha_{ij} / \sum_{i \neq j} \alpha_{ij}$, where $\alpha_{ij}$ is the value of goods originating in state $i$ with destination in neighboring state $j$. Data on the value of goods shipped from state of origin to state of destination come from the 1993 and 1997 Commodity Flows Surveys, U.S. Bureau of Transportation Statistics (obtained from the relevant CDs).

*Output:* Real GDP by state for the private non-farm sector comes from the BEA (source: http://www.bea.gov/regional/gsp). The series is discontinued in 1997 due to the industry classification system change from SIC (Standard Industrial Classification) to NAICS (North American

Industry Classification System). In calculating output growth rates, we exploit both versions of data in 1997 to be consistent with industry definitions.

*Labor:* Private nonfarm employment as a measure of labor is obtained from the BEA (source: http://www.bea.gov/regional/spi).

*Income shares of labor and capital:* Labor income shares, $S_{YL}$, are calculated at the U.S. state level following the procedure proposed by Gollin (2002). First the wage and salary income of employees is imputed as labor income. Then the average labor income of employees is calculated and the same average labor income is imputed to the self-employed. The sum of measured labor income of employees and imputed labor income of the self-employed is used as a measure of total labor income. Dividing total labor income by total income provides an estimate of the labor income share at the state level. State-level data on total income, employees' wages, and income of the self-employed for the private nonfarm business sector are available from the BEA (source: http://www.bea.gov/regional/spi). Given labour's share, the share of capital, $S_{YK}$, is then determined residually as $1 - S_{YL}$.

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Table 1. Parameter Estimates of Linear Model

| Independent Variable | Without Spillovers | With Spillovers |
|---|---|---|
| year trend | 0.0005 | 0.0007 |
| | (0.0001) | (0.0001) |
| growth of capital spending ($\hat{g}_c$) | 0.005 | -0.004 |
| | (0.004) | (0.005) |
| growth of O&M spending ($\hat{g}_{om}$) | 0.008 | -0.016 |
| | (0.009) | (0.011) |
| growth of capital spillover ($\hat{S}_c$) | - | 0.052 |
| | | (0.012) |
| growth of O&M spillover ($\hat{S}_{om}$) | - | 0.411 |
| | | (0.035) |
| No. of observations | 1104 | 1104 |

Notes: Estimation method is OLS and standard errors are reported in parentheses.

The dependent variable is TFP growth and regressions include a constant and state dummies.

Table 2. Average Output Elasticities by State, 1978-2000 (Semiparametric Estimates)

| State | $\theta_1(Z_{it})$ | $\theta_2(Z_{it})$ | $\theta_3(Z_{it})$ | $\theta_4(Z_{it})$ | State | $\theta_1(Z_{it})$ | $\theta_2(Z_{it})$ | $\theta_3(Z_{it})$ | $\theta_4(Z_{it})$ |
|---|---|---|---|---|---|---|---|---|---|
| NORTHEAST | | | | | Virginia | 0.0010 | -0.012 | 0.037 | 0.376 |
| | | | | | (VA) | (0.001) | (0.003) | (0.002) | (0.002) |
| Maine | 0.0009 | -0.007 | 0.046 | 0.409 | West Virginia | -0.0029 | -0.014 | 0.046 | 0.385 |
| (ME) | (0.001) | (0.003) | (0.004) | (0.009) | (WV) | (0.001) | (0.003) | (0.003) | (0.003) |
| New Hampshire | -0.0008 | -0.017 | 0.059 | 0.427 | North Carolina | -0.0012 | -0.017 | 0.040 | 0.378 |
| (NH) | (0.001) | (0.004) | (0.006) | (0.012) | (NC) | (0.001) | (0.003) | (0.002) | (0.002) |
| Vermont | -0.0003 | -0.015 | 0.058 | 0.438 | South Carolina | -0.0006 | -0.016 | 0.039 | 0.380 |
| (VT) | (0.001) | (0.004) | (0.006) | (0.012) | (SC) | (0.001) | (0.003) | (0.002) | (0.003) |
| Massachusetts | -0.0007 | -0.016 | 0.040 | 0.376 | Georgia | -0.0101 | -0.025 | 0.061 | 0.392 |
| (MA) | (0.001) | (0.002) | (0.003) | (0.002) | (GA) | (0.001) | (0.001) | (0.004) | (0.002) |
| Rhode Island | -0.0017 | -0.016 | 0.042 | 0.382 | Florida | -0.0042 | -0.019 | 0.047 | 0.383 |
| (RI) | (0.001) | (0.003) | (0.003) | (0.003) | (FL) | (0.001) | (0.003) | (0.003) | (0.002) |
| Connecticut | -0.0007 | -0.015 | 0.040 | 0.377 | Kentucky | -0.0082 | -0.026 | 0.055 | 0.389 |
| (CT) | (0.001) | (0.003) | (0.003) | (0.002) | (KY) | (0.002) | (0.001) | (0.006) | (0.004) |
| New York | 0.0031 | 0.0004 | 0.037 | 0.388 | Tennessee | -0.0062 | -0.028 | 0.048 | 0.385 |
| (NY) | (0.001) | (0.001) | (0.001) | (0.004) | (TN) | (0.001) | (0.001) | (0.002) | (0.001) |
| Pennsylvania | -0.0021 | -0.010 | 0.059 | 0.438 | Mississippi | -0.0001 | -0.020 | 0.035 | 0.372 |
| (PA) | (0.001) | (0.003) | (0.004) | (0.007) | (MS) | (0.001) | (0.002) | (0.001) | (0.001) |
| New Jersey | 0.0026 | -0.005 | 0.035 | 0.379 | Alabama | 0.0021 | -0.013 | 0.034 | 0.371 |
| (NJ) | (0.0004) | (0.002) | (0.001) | (0.003) | (AL) | (0.001) | (0.002) | (0.001) | (0.001) |
| | | | | | Oklahoma | -0.0004 | -0.021 | 0.036 | 0.374 |
| MIDWEST | | | | | (OK) | (0.001) | (0.002) | (0.001) | (0.001) |
| | | | | | Texas | -0.0044 | -0.020 | 0.047 | 0.381 |
| Wisconsin | 0.0027 | -0.005 | 0.035 | 0.380 | (TX) | (0.002) | (0.002) | (0.004) | (0.003) |
| (WI) | (0.001) | (0.002) | (0.001) | (0.003) | Arkansas | 0.0023 | -0.008 | 0.035 | 0.379 |
| Michigan | -0.0037 | -0.025 | 0.074 | 0.461 | (AR) | (0.001) | (0.002) | (0.001) | (0.003) |
| (MI) | (0.001) | (0.003) | (0.005) | (0.010) | Louisiana | -0.0044 | -0.022 | 0.046 | 0.382 |
| Illinois | 0.0025 | -0.002 | 0.038 | 0.388 | (LA) | (0.002) | (0.002) | (0.004) | (0.003) |
| (IL) | (0.001) | (0.002) | (0.001) | (0.004) | | | | | |
| Indiana | 0.0034 | -0.006 | 0.033 | 0.374 | WEST | | | | |
| (IN) | (0.001) | (0.002) | (0.001) | (0.002) | | | | | |
| Ohio | 0.0031 | -0.008 | 0.033 | 0.372 | Idaho | -0.0068 | -0.020 | 0.054 | 0.386 |
| (OH) | (0.001) | (0.002) | (0.001) | (0.001) | (ID) | (0.001) | (0.002) | (0.003) | (0.002) |
| North Dakota | -0.0038 | -0.021 | 0.045 | 0.382 | Montana | -0.0071 | -0.026 | 0.052 | 0.385 |
| (ND) | (0.001) | (0.002) | (0.003) | (0.003) | (MT) | (0.001) | (0.001) | (0.003) | (0.002) |
| South Dakota | -0.0026 | -0.023 | 0.040 | 0.377 | Wyoming | -0.0220 | -0.022 | 0.096 | 0.414 |
| (SD) | (0.001) | (0.001) | (0.003) | (0.002) | (WY) | (0.002) | (0.001) | (0.006) | (0.006) |
| Nebraska | -0.0055 | -0.027 | 0.046 | 0.384 | Nevada | -0.0113 | -0.023 | 0.065 | 0.393 |
| (NE) | (0.001) | (0.001) | (0.002) | (0.002) | (NV) | (0.001) | (0.001) | (0.004) | (0.003) |
| Kansas | 0.0006 | -0.017 | 0.035 | 0.373 | Utah | -0.0060 | -0.025 | 0.049 | 0.383 |
| (KS) | (0.001) | (0.002) | (0.001) | (0.002) | (UT) | (0.001) | (0.001) | (0.004) | (0.002) |
| Minnesota | -0.0016 | -0.023 | 0.037 | 0.375 | Colorado | -0.0007 | -0.017 | 0.039 | 0.375 |
| (MN) | (0.001) | (0.001) | (0.001) | (0.002) | (CO) | (0.001) | (0.002) | (0.002) | (0.002) |
| Iowa | -0.0011 | -0.023 | 0.036 | 0.373 | Arizona | -0.0111 | -0.020 | 0.067 | 0.391 |
| (IA) | (0.001) | (0.001) | (0.001) | (0.001) | (AZ) | (0.002) | (0.001) | (0.006) | (0.004) |
| Missouri | 0.0017 | -0.015 | 0.033 | 0.370 | New Mexico | -0.0070 | -0.020 | 0.062 | 0.411 |
| (MO) | (0.001) | (0.002) | (0.001) | (0.001) | (NM) | (0.001) | (0.002) | (0.004) | (0.008) |
| | | | | | Washington | -0.0016 | -0.021 | 0.039 | 0.375 |
| SOUTH | | | | | (WA) | (0.001) | (0.002) | (0.002) | (0.002) |
| | | | | | Oregon | 0.0023 | -0.012 | 0.033 | 0.371 |
| Delaware | -0.0032 | -0.016 | 0.046 | 0.382 | (OR) | (0.001) | (0.002) | (0.001) | (0.002) |
| (DE) | (0.002) | (0.003) | (0.004) | (0.003) | California | -0.0004 | -0.002 | 0.047 | 0.417 |
| Maryland | -0.0037 | -0.016 | 0.047 | 0.393 | (CA) | (0.001) | (0.001) | (0.002) | (0.004) |
| (MD) | (0.001) | (0.003) | (0.003) | (0.004) | | | | | |

Notes: Estimation method is partially linear semiparametric smooth coefficient approach. See also Table 1.

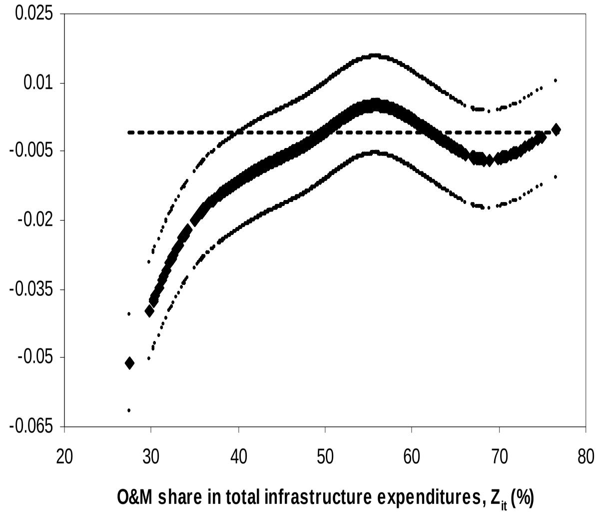
Table 3. Baseline Results and Sensitivity Analysis

| Independent Variable | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| NONLINEAR PART: AVERAGE COEFFICIENTS | | | | | | |
| growth of capital spending ($\hat{g}_c$) | -0.002 | -0.0001 | -0.003 | -0.004 | -0.008 | -0.007 |
| | (0.00021) | (0.00060) | (0.00021) | (0.00027) | (0.00021) | (0.00032) |
| growth of O&M spending ($\hat{g}_{om}$) | -0.017 | -0.071 | -0.021 | -0.019 | -0.029 | -0.016 |
| | (0.00038) | (0.00346) | (0.00047) | (0.00050) | (0.00056) | (0.00032) |
| growth of capital spillover ($\hat{S}_c$) | 0.046 | 0.041 | 0.050 | 0.056 | 0.083 | 0.049 |
| | (0.00059) | (0.00363) | (0.00060) | (0.00099) | (0.00051) | (0.00083) |
| growth of O&M spillover ($\hat{S}_{om}$) | 0.388 | 0.500 | 0.375 | 0.361 | 0.354 | 0.291 |
| | (0.00085) | (0.00548) | (0.00074) | (0.00154) | (0.00121) | (0.00099) |
| LINEAR PART | | | | | | |
| year trend | 0.0007 | - | 0.0012 | 0.0006 | 0.0003 | 0.0003 |
| | (0.00008) | | (0.0002) | (0.00008) | (0.00008) | (0.00009) |
| unemployment rate | - | - | -0.001 | - | - | - |
| | | | (0.039) | | | |
| federal employees | - | - | 0.651 | - | - | - |
| | | | (0.201) | | | |
| state and local employees | - | - | -1.240 | - | - | - |
| | | | (0.260) | | | |
| federal revenue | - | - | 0.372 | - | - | - |
| | | | (0.139) | | | |
| tax burden | - | - | -0.051 | - | - | - |
| | | | (0.085) | | | |
| working population | - | - | 0.267 | - | - | - |
| | | | (0.084) | | | |
| nonwhite | - | - | 0.026 | - | - | - |
| | | | (0.031) | | | |
| female | - | - | -0.006 | - | - | - |
| | | | (0.331) | | | |
| No. of observations | 1104 | 1008 | 1056 | 1104 | 1104 | 1104 |

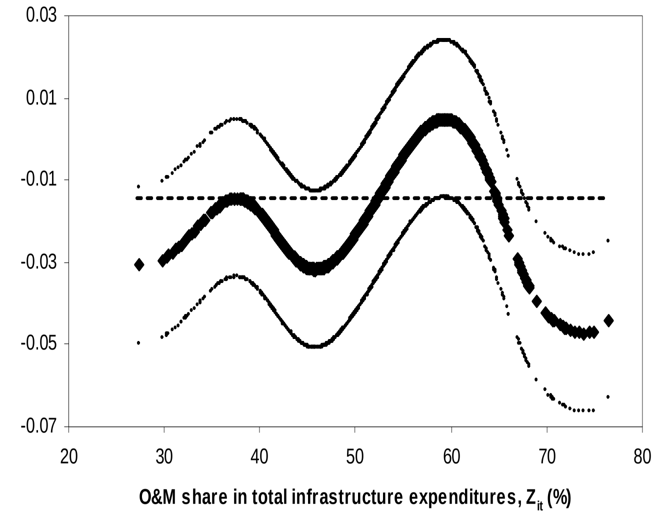
Notes: The table presents coefficients obtained from the estimation of eq. (5). Column (1) reports the baseline results. In column (2) we use the local generalized-method-of-moments approach to examine the impact of potential endogenous effects in the estimated coefficients. In column (3) a number of variables are employed as additional controls. In column (4) a second state variable is used, namely the O&M share in the sum of the two spillover indices. In column (5) the spillover variables included in the regression have been computed by weighting different states only with information on relative economic activity. In column (6) the regression is run for highways and roads. The dependent variable is TFP growth ($\widehat{TFP}$). All regressions include a constant and in addition regressions in columns (1) and (3)-(6) include state dummies. Standard errors are reported in parenthesis.

Table A1. Data Averages by State (%, 1978-2000)

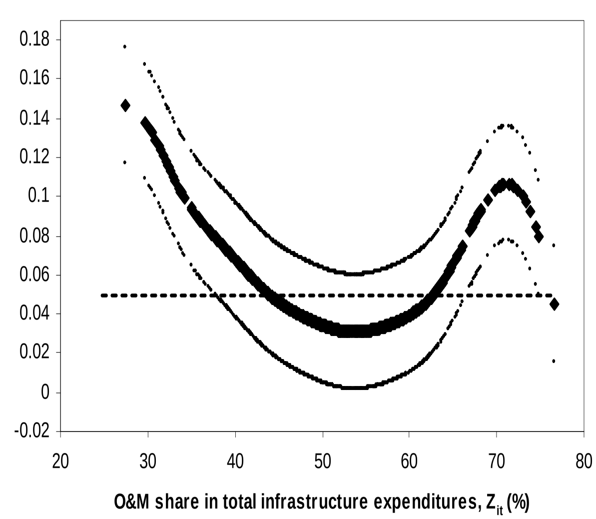
| State | Growth Rate of | | | | | Level of | |
|---|---|---|---|---|---|---|---|
| | Total Factor Productivity | Own-State Spending | | Spillovers | | Output Share of Labor | O&M Share in Total Spending |
| | | Capital | O&M | Capital | O&M | | |
| | $(\hat{TFP})$ | $(\hat{g}_c)$ | $(\hat{g}_{om})$ | $(\hat{S}_c)$ | $(\hat{S}_{om})$ | $(S_{YL})$ | $\left(\frac{g_{om}}{g_c+g_{om}}\right)$ |
| Alabama (AL) | 0.75 | 1.25 | 2.20 | 1.38 | 2.44 | 63.67 | 52.65 |
| Arizona (AZ) | 0.98 | 4.34 | 5.71 | 4.94 | 5.68 | 66.05 | 41.76 |
| Arkansas (AR) | 0.69 | 0.56 | 2.22 | 1.73 | 2.78 | 64.32 | 55.00 |
| California (CA) | 1.17 | 4.01 | 4.39 | 2.94 | 3.73 | 68.95 | 61.82 |
| Colorado (CO) | 0.93 | 2.10 | 4.37 | 3.78 | 4.70 | 72.92 | 50.09 |
| Connecticut (CT) | 1.79 | 3.02 | 1.94 | 2.94 | 3.09 | 68.68 | 50.49 |
| Delaware (DE) | 1.42 | 2.49 | 2.78 | 3.01 | 3.78 | 73.65 | 48.70 |
| Florida (FL) | 1.04 | 3.10 | 5.44 | 3.69 | 4.54 | 59.73 | 47.22 |
| Georgia (GA) | 1.33 | 2.84 | 3.19 | 3.65 | 4.80 | 69.79 | 41.99 |
| Idaho (ID) | 0.96 | 0.65 | 3.45 | 2.55 | 3.32 | 64.48 | 44.58 |
| Illinois (IL) | 0.88 | -0.08 | 2.49 | 1.32 | 2.11 | 69.09 | 57.57 |
| Indiana (IN) | 0.65 | 1.11 | 2.63 | 1.14 | 2.26 | 69.67 | 54.78 |
| Iowa (IA) | 0.68 | 1.31 | 0.95 | 0.55 | 1.62 | 63.47 | 49.61 |
| Kansas (KS) | 0.51 | 1.10 | 3.53 | 1.45 | 2.37 | 64.25 | 51.48 |
| Kentucky (KY) | 0.26 | 1.60 | 2.77 | 0.74 | 1.83 | 64.98 | 44.42 |
| Louisiana (LA) | 0.45 | -0.35 | 1.82 | 0.51 | 1.62 | 63.57 | 47.00 |
| Maine (ME) | 0.89 | -0.50 | 1.69 | 1.89 | 2.18 | 66.57 | 60.07 |
| Maryland (MD) | 0.89 | -0.58 | 3.46 | 1.95 | 3.21 | 58.44 | 51.07 |
| Massachusetts (MA) | 1.71 | 5.30 | 1.54 | 2.45 | 3.35 | 72.44 | 50.06 |
| Michigan (MI) | 0.16 | 0.77 | 2.57 | 0.70 | 1.60 | 71.02 | 65.15 |
| Minnesota (MN) | 0.97 | 1.93 | 2.05 | 2.44 | 3.10 | 71.49 | 49.04 |
| Mississippi (MS) | 0.79 | 0.58 | 1.94 | 1.05 | 2.17 | 58.83 | 50.40 |
| Missouri (MO) | 0.73 | 1.50 | 2.90 | 1.22 | 2.45 | 69.89 | 51.92 |
| Montana (MT) | 0.005 | -1.15 | 1.43 | 0.48 | 1.11 | 60.97 | 44.34 |
| Nebraska (NE) | 0.80 | 0.73 | 1.29 | 1.51 | 2.41 | 65.37 | 45.63 |
| Nevada (NV) | 0.75 | 7.21 | 6.39 | 5.48 | 6.31 | 72.65 | 41.06 |
| New Hampshire (NH) | 1.53 | -1.52 | 2.35 | 4.22 | 4.14 | 64.84 | 61.30 |
| New Jersey (NJ) | 1.22 | 2.26 | 3.71 | 2.47 | 2.82 | 64.62 | 55.77 |
| New Mexico (NM) | 0.83 | 2.80 | 5.20 | 2.28 | 3.23 | 61.61 | 50.51 |
| New York (NY) | 1.20 | 2.89 | 1.49 | 1.63 | 2.57 | 68.01 | 58.22 |
| North Carolina (NC) | 1.24 | 2.33 | 5.16 | 2.97 | 3.83 | 68.57 | 50.07 |
| North Dakota (ND) | 0.24 | -0.19 | 1.09 | 0.55 | 0.85 | 61.13 | 48.11 |
| Ohio (OH) | 0.61 | 1.82 | 2.09 | 0.74 | 1.85 | 69.78 | 54.09 |
| Oklahoma (OK) | 0.15 | 2.52 | 2.24 | 0.87 | 2.00 | 64.46 | 50.18 |
| Oregon (OR) | 0.80 | 2.46 | 2.13 | 2.17 | 3.04 | 68.10 | 53.01 |
| Pennsylvania (PA) | 0.96 | 0.96 | 1.99 | 0.97 | 1.82 | 66.38 | 63.64 |
| Rhode Island (RI) | 1.56 | 1.27 | 2.30 | 2.54 | 2.04 | 64.25 | 50.27 |
| South Carolina (SC) | 1.11 | 5.27 | 4.13 | 2.26 | 3.51 | 64.84 | 51.14 |
| South Dakota (SD) | 1.08 | 2.47 | 1.00 | 2.15 | 2.78 | 58.29 | 48.14 |
| Tennessee (TN) | 0.90 | 2.37 | 2.05 | 2.25 | 3.43 | 69.67 | 45.02 |
| Texas (TX) | 0.52 | 3.09 | 3.99 | 2.68 | 3.77 | 70.92 | 46.78 |
| Utah (UT) | 0.61 | 3.87 | 5.18 | 3.35 | 4.36 | 69.99 | 45.44 |
| Vermont (VT) | 1.13 | -0.46 | 3.41 | 2.83 | 2.88 | 68.51 | 64.08 |
| Virginia (VA) | 1.28 | 0.73 | 4.10 | 2.92 | 4.04 | 62.80 | 52.11 |
| Washington (WA) | 0.95 | 2.82 | 3.29 | 3.12 | 3.97 | 67.65 | 49.05 |
| West Virginia (WV) | 0.34 | -0.19 | 0.94 | -0.85 | 0.25 | 61.88 | 49.96 |
| Wisconsin (WI) | 0.55 | 3.04 | 1.49 | 1.28 | 2.37 | 67.12 | 55.77 |
| Wyoming (WY) | 0.17 | 1.94 | 2.62 | 0.12 | 1.18 | 63.65 | 35.66 |
| Mean | 0.86 | 1.82 | 2.86 | 2.06 | 2.90 | 66.29 | 50.96 |
| Std. Dev. | 0.41 | 1.76 | 1.37 | 1.28 | 1.22 | 4.00 | 6.25 |



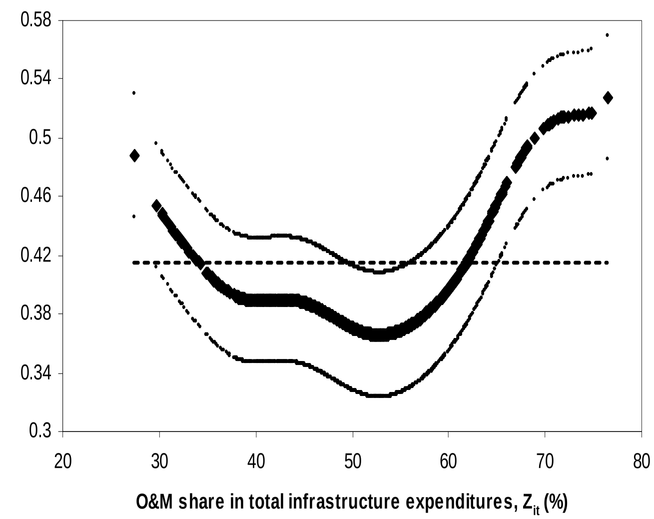

(a) Output elasticity of own-state capital spending, $\theta_1(Z_{it})$




(b) Output elasticity of own-state O&M spending, $\theta_2(Z_{it})$




(c) Output elasticity of capital spending by other states, $\theta_3(Z_{it})$




(d) Output elasticity of O&M spending by other states, $\theta_4(Z_{it})$

Figure 1: Coefficient Estimates for the Nonparametric Part of Model 2

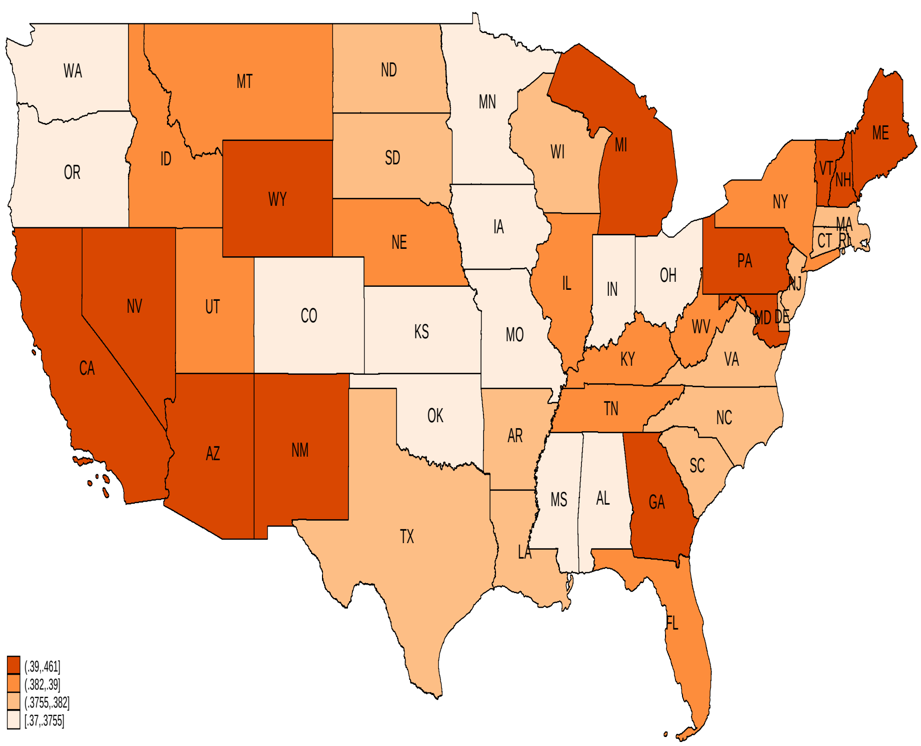



Figure 2: Output elasticity of O&M spending by other states, $\theta_4(Z_{it})$: Mean estimates by state, 1978-2000