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Article

Do transportation infrastructure contracts enhance spending efficiency? Examining state highway construction programs

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Abstract: This study examines the impact of state highway construction contracts on state spending efficiency controlling for production structure, service demands, and situational factors. The theoretical argument is that because highway construction projects are relatively large in scale, complex, and can be monitored through objective performance measurement, state highway construction programs may save government production costs through contracts. Contracting helps highway producers achieve efficiency by optimizing production size based on workload and task complexity. The unit of analysis is 48 state governments' highway construction contracts from 1998 to 2008. Through a two-stage analysis method including a Total Function Productivity (TFP) index and system dynamic panel data analysis, the results suggest that highway construction contracts enhance state highway spending efficiency, especially for large-scale construction projects.

Keywords: state government; infrastructure contract; highway; spending efficiency; Total Function Productivity (TFP) index

1. Introduction

This paper examines the impact of state highway construction contracts on highway spending efficiency, controlling for production structure, service demands, and other situational factors in state governments. State highway construction programs are ideal for analysis due to their substantial and increasing funding by state governments. In 2023, state transportation spending reached $213.8 billion, marking a 12.9% increase from the previous year (National Association of State Budget Officers, 2023). Furthermore, highway systems are essential for subnational economic growth, serving both private sector transportation and individual commuting needs (Garcia-Mila and McGuire, 1992; Lobo and Rantisi, 1999). A critical issue facing state governments is how to undertake increasingly complex transportation projects efficiently.

In 2014, state governments aggregately contracted out 27,684 highway construction projects with a total value of $41.8 billion, amounting to about twice as much as was contracted in 1999 (American Road and Transportation Builders Association, 2015). This mirrors the long-standing trend of the public sector's frequent use of contracting (Henig, 1989; Hefetz and Warner, 2011; Savas, 2000). Contracting generates competition which could subsequently increase efficiency (Kettl, 1993; Osborne and Gaebler, 1992; Owen, 1998; Savas, 2000). However, other studies suggest that the efficiency of contracting depends on external factors like specific goods, services, and market availability (Bel and Costas, 2006; Bel and Fageda, 2007; Bel and Mur, 2009; Hefetz and Warner, 2011; Hefetz, et al., 2012; Nelson and Foster, 1999; Warner and Hefetz, 2003; Warner and Hefetz, 2012). In fact, Grandy (2009) highlights the need to consider measures beyond a business-oriented approach, emphasizing citizen participation and equity. This suggests a wider reflection on efficiency from an economic perspective that includes implicit and explicit costs, rather than solely a business approach to contracting.

Due to the lack of consensus on the outcomes of contracting, this study aims to empirically assess state highway construction contracts through a two-stage analysis. The first stage calculates Malmquist’s Total Function Productivity (TFP) index through the relationship between state highway construction cost inputs and road mileage with road conditions and traffic flow as an output. The second stage uses system dynamic panel data analysis (SDPD) to examine factors impacting highway spending efficiency. The results indicate that highway construction contracts enhance state highway spending efficiency, especially for large-scale construction projects.

The study’s findings provide marginal contribution for both literature and practices. For literature, the empirical results support the theoretical argument that contracts lower overall costs (Savas, 2000). This is especially true in state highway construction and maintenance cases where transactional costs are relatively high, demand for highway construction is seasonal, and project acquisition is complex due to a multitude of the projects responding to normal growth patterns (Hancher and Werkmeister, 2001; Ribreau, 2004). Furthermore, to our knowledge, studies in which the efficiency of state highway contracts measured through the TFP index are rarely conducted.

The study demonstrates that the implementation of state highway contract efficiency measurements is possible if contracting cost data is available. Gauging and measuring the efficiency of contracts, particularly related to highway construction has not been analyzed in the literature in detail. This is due to data limitations when trying to compile a state level panel data set and the difficulties in measuring efficiency, particularly when comparing contracted work to in-house work. Trying to determine if a contract was effective is an additional step of analysis that has not been undertaken; in fact, Department of Transportation (DOTs) simply measure the completeness of a project rather than the efficiency of the complete work. Additionally, the data often does not have sufficient detail to accurately parse the cost of a contract when determining the work done due to the way a contract is written, the type of work being performed, the cost of materials, etc. This is because of various contract mechanisms employed by state DOTs.

The rest of this paper is organized as follows: a section providing a literature review and conceptual framework including background information on highway construction and contracting, a section presenting the empirical model, data, and methodology, a section presenting the empirical results, and a final section providing a conclusion and potential direction for future research.

2. Literature review

While contracting involves outsourcing public services to private firms, not all types of public goods and services are appropriate for contracting due to their varying operational characteristics (Savas, 2000). Appropriate service contracts include those that 1) require multiple producers, 2) promote efficiency and effectiveness in using public resources, 3) can achieve economies of scale, and 4) can relate costs with benefits (Savas, 2000, p. 103). Contracting is a widely researched topic. Early literature viewed contracting as a means to "shrink government" (Morgan et al., 1988; Morgan and England, 1988; Terry, 2005), while recent literature asserts that for some types of public service, contracting enhances efficiency (Boyne, 1998; Bouché and Volden, 2011; Fernandez et al., 2008; Greene, 2002; Hefetz and Warner, 2011; Hefetz et al., 2012; Levin and Tadelis, 2010; Savas, 2000). Local governments expect cost reductions and improved efficiency by using contracts (Heftez and Warner, 2011; Hefetz et al., 2014; Kelman, 2002; Megginson and Netter, 2001). This is true when a contract is easy to specify and performance is easy to measure (Shetterly, 2000; Williamson, 1991).

Contracting is often seen as a response to fiscal stress (Boyne, 1998; Geys and Sorensen, 2016; Zhang et al., 2017) and a way to deliver public services more cost-effectively (Brown and Potoski, 2003; Fernandez et al., 2008; Geys and Sorensen, 2016; Kelman, 2002). Rising service demands and financial constraints drive public officials to seek more cost-efficient service provision methods (Brown et al., 2008; Dilger et al., 1997; Hebdon and Jalette, 2008; Kodrzycki, 1994; Wei et al., 2022).

Although the literature lacks consensus, transaction cost theorists have found empirical support for the claim that contracting can lower overall costs under the right circumstances (Brown and Potoski, 2003; Fernandez et al., 2008; Greene, 2002; Hefetz and Warner, 2011; Savas, 2000). In a competitive market with multiple private vendors, contracting tends to increase transparency and viability of the market, improving efficiency and reducing service delivery costs (Brown and Potoski, 2003; Hefetz and Warner, 2011; Hefetz et al., 2014). However, unlike competitive markets, services in incomplete markets face challenges in contract management and high-performance monitoring costs making them unsuitable candidates. (Brown and Potoski, 2003; Hefetz and Warner, 2011; Levin and Tadelis, 2010).

2.1. Highway construction background and contracts

In 1998, transportation topped the list among 2921 state government programs for the highest volume of contracting (Savas, 2000). Highway construction can be assessed by measurable service quantity and quality indicators. For example, highway construction quantity can be measured by the total number of new lane miles built in a specific period. Highway construction quality can be measured through road surface conditions with caveats based on specific regional climates. Thus, contracts for highway construction seem to be an appropriate operational function among other highway service activities for state DOTs.

Among all levels of government, state DOTs are responsible for about half of all road miles across the U.S. (Puentes and Prince, 2003; Rall et al., 2011). Several developments have changed the financing and delivery methods of highway construction projects. State agencies have increasingly adopted contracts for governmental functions including transportation. Transportation contracts have been driven by declines in traditional revenue sources, such as the federal gasoline tax, which has not been adjusted since 1993, eroding due to increasing fuel efficiency and inflation. Additionally, population growth has increased service demands leading DOTs to contract functions traditionally handled in-house, such as design, construction, and maintenance (Olberding, 1995). In 2014, state governments aggregately contracted out 27,684 highway construction projects totaling $41.8 billion, nearly double the amount from 1999 (American Road and Transportation Builders Association—ARTBA, 2015).

Transportation agencies consider multiple factors in their decisions to contract, each impacting the decision-making process to varying extents (Warne, 2003). Staff constraints are the main reason for contracting (Hancher et al., 2006). Another key factor in contract decisions is highway service demand growth (Hancher et al., 2006). Survey results from 30 states indicate that contracts occurred in a variety of operational functions like design, environment, right-of-way, and surveying (Hancher et al., 2006).

Zambrano et al. (1998) examined the Texas Department of Transportation's contracts and found increased contract consideration for previously uncontracted services due to workforce reductions, inexperience, and legislative mandates. Warne (2003) attributed increasing contracts to the Transportation Equity Act for the 21st Century which boosted funding to states and staffing levels. These findings align with other research that suggest a few reasons for contracting capital programs: a movement in DOTs to address stall projects, states using capital program contracts to develop strategies for growth, and a meshing of the above factors (Science Applications International Corporation, 2003).

For state DOTs, highway program contracts save costs, increase service levels, optimize government resources, acquire specialized skills, manage peak demands, and implement political directives (Ribreau, 2004, p. 3). For highway maintenance programs, contracted services address public expectations, improve the use of limited resources, reduce life-cycle costs, and increase competition (American Association of State Highway and Transportation Officials, 2002). Specifically, Hancher and Werkmeister (2001) documented that for state highway construction programs contracting can address seasonal demands, stabilizing DOTs' workforce year-round. Potential disadvantages of contracting listed by Hancher and Werkmeister (2001) included higher transaction costs to ensure quality and timeliness, the loss of skilled in-house manpower, legal complexities in awarding contracts, the necessity to recruit employees with new skills, and the impact on the state DOT's reputation and ability to mentor new engineers. Based on the transportation contract literature, we hypothesize that the percent of state highway construction contract value to total state highway construction cost is positively associated with state highway spending efficiency. Such relationship is controlled by state highway production structure and service demand levels, among many other situational factors. This is because highway construction contracts reduce transactional costs (Hancher and Werkmeister, 2001), stabilize seasonal highway construction spending (Ribreau, 2004), and address a multitude of projects dealing with normal growth patterns (Warne, 2003).

2.2. Malmquist's Total Function Productivity (TFP) index

In this study we use Malmquist's Total Function Productivity (TFP) index as an indicator for state highway spending efficiency. The TFP index has become the standard approach in productivity measurement over time, especially when nonparametric specification is applied to microdata (Bjurek, 1996; Forsund, 2016). The TFP measures an organization's efficiency change from one period (y_t) to another (y_{t+1}) based on the ratio of the organization's inputs and outputs. It reflects changes in the organization's overall efficiency over time due to (1) technical progress (e.g., better operation such as management decisions and input mixes) and (2) efficiency changes that catch up as production processes continue (Bjurek, 1996).

The TFP is built based on the basic concepts of Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH) (Dario and Simar, 2007). In DEA, economic efficiency refers to the distance between the quantity of input and output which defines a frontier: the best production possibility set for all analyzed producers (Muller, 2008). Productivity or efficiency analysis is related to a producer's efficiency in transforming inputs to outputs (Mueller, 2008). Technical efficiency is defined by the microeconomic concept of Pareto's efficiency (Dario and Simar, 2007; Mueller, 2008). An input-output vector is already efficient when no further improvement is possible without losing part of the desirable outcome (Dario and Simar, 2007).

DEA is a linear mathematical programing technique using input data of an organization to calculate a piecewise linear hull that envelops the observed outcomes or outputs of the organization (Sherman and Zhu, 2006). DEA uses quantified input and output data for a group of organizations to identify the best possible practices or frontiers. Each organization's efficiency is measured by a distance between its input-output quantity that defines the best possible frontier for a firm in its cluster (Dario and Simar, 2007, p. 14). Due to this measurement construction, the efficiency value of any organization depends on the structure of the production possibility sets and the samples of originations included in the analysis (Muller, 2008).

The FDH is a general version of DEA relying only on the free disposability assumption for the production possibility set, rather than restricting itself to DEA frontier technology. Efficiency reflects both input-output ratios and a producer's ability to select the "right technically efficient input-output vector in light of prevailing input and output prices" (Dario and Simar, 2007, p. 15). The definition of the right production possibility set varies based on allocative efficiency and scale economy. Allocative efficiency measures the producer's success in choosing an optimal set of input prices. The mix of input quantity and types can be changed based on input cost. For example, a firm would reduce labor hours and rely more on information technology (i.e., capital) to produce the same products if the technological cost is cheaper than labor cost, hence, increasing efficiency due to increasing allocative efficiency. This differs from the technical efficiency concept associated with a production frontier, which measures the producer's success in producing maximum output from a given set of inputs.

The Malmquist TFP adds a time dimension to the FDH efficiency by measuring the proportional change in all observed input (or output) quantities from current year (time t) to the next year (time t + 1) (Bjurek, 1996). This definition is presented in Equations (1) and (2) below.

$$MI_k(y_k x_k x_{t+1}) = \frac{E_k^I(y_k x_k)}{E_k^I(y_k x_{t+1})}, k = t, t+1 \tag{1}$$

where *MI* is the Malmquist Productivity Index for Input Change, E_k^I is the input-oriented efficiency score, *y* is output, *x* is input, *k* is time, *t* + 1 is the next year period.

Equation (1) states that the input quantity index is a ratio between the standard input efficiency measure for a production unit observed at time *t*, and a measure corresponding to an input efficiency measure for a combination of outputs at time *t* and inputs at time *t* + 1. If the index is below one, fewer inputs were used in production at time *t* + 1 than at time *k* for the given technology and level of outputs at time *k*. Note that Equation (1) measures only change in observed input quantities between time *k* and *t* + 1. To measure the change in observed output quantities between time *k* and *t* + 1, Equation (2) is used.

$$MO_k(y_k y_{t+1} x_k) = \frac{E_k^O(y_{t+1} x_k)}{E_k^O(y_k x_k)}, k = t, t+1 \tag{2}$$

where MO is the Malmquist Productivity Index for Output Change, the E_k^O output-oriented efficiency.

Equation (2) states the output quantity index is a ratio between a measure corresponding to an output efficiency measure for a combination of output at time *t* + 1, and inputs at time *k* and the standard output efficiency measure for a production unit observed at time *k*. If the index is less than one, more outputs are produced at time *t* + 1 than at time *k* for the given technology and level of outputs at time *k*.

In the basic DEA concept, the number of (*n*) input or output oriented model is chosen based on the nature of production processes and other necessary conditions. For example, in a private-sector factory, an output-oriented model may be appropriate given that the production process focuses on increasing outputs with fixed inputs (e.g., stock investment). In the public sector (e.g., public school service and welfare programs), an input-oriented model is appropriate since service demands and outputs are fixed (i.e., governments do not deny services to eligible clients by law); the only factor that can increase efficiency are inputs (or government spending). Malmquist's Total Function Productivity (TFP) index measures both input and output changes from time *k* to *t* + 1; hence, being named Malmquist's Total Function Productivity (TFP) index.

$$TFP_k = \frac{MO_k(y_{k,} y_{t+1,} x_k)}{MI_k(y_k x_k x_{t+1})} = \frac{E_k^o(y_{t=1} x_k)/E_k^o(y_k x_k)}{E_k^I(y_k x_k)/E_k^1(y_k x_{t+1})}, k = 1, t+1 \tag{3}$$

Equation (3) presents Malmquist's Total Function Productivity (TFP) index, a ratio of marginal change between an output and input from time *k* to *t* + 1. If the TFP is greater than one, productivity increases over time based on measurement for both input and output orientations. If the TFP is less than one, productivity decreases over time, and if the TFP is equal to one, productivity remains unchanged. As discussed above, the productivity changes over time are based on two factors: (1) change in efficiency (or producer's catching up), and (2) change in the frontiers, i.e., technical change. If we want to incorporate technical change, the geometric mean of the productivity indexes for both *k* and *t* + 1 can be calculated and is defined as shown in Equation (4) below.

$$MTFP_{k,t+1} = \sqrt{MTFP_k MTFP_{t+1}} = \sqrt{\frac{MO_k(y_k y_{t+1} x_k)}{MI_k(y_k x_k x_{t+1})} \frac{MO_{t+1}(y_k y_{t+1} x_{t+1})}{MI_{t+1}(y_{t+1} x_k x_{t+1})}} \quad (4)$$

2.3. How is TFP used in literature?

TFP is widely used in policy literature especially for industrial development and across public and private sectors to understand productivity changes. Fare et al. (1998) and Grosskopf (2003) both conducted extensive literature surveys on TFP's applications. For this study, due to limited space, we will review only pertinent examples. First, in the public sector, Inmaculada et al. (2011) used TFP to understand the determinants of national economic growth (i.e., change in gross value added (GVA)—that is, national productivity) across 14 European Union countries from 1980–2002. They used inputs like capital investment and employment, estimating total productivity change using TFP. Their independent variables included human capital and infrastructure changes. The authors augmented the model by incorporating the capital-labor ratio, the ratio of public and private infrastructure, the service sector, and the dummy variable whether the economic growth in a country is greater or lower than the mean of the sample growth rate. The results suggest that all explanatory variables explain the TFP. This study guided policymakers in determining the optimal amount of public infrastructure investment along with promoting capital resource endowment and service sector development to target growth. Another example is from Alam's (2001) work in which TFP in 1981–2000 was calculated to understand the effect of U.S. banking deregulation in 1983. The study assumes that increased productivity in the overall U.S. banking industry resulted from notable financial innovations after deregulations. This example illustrates how TFP is used in performance measurement and program evaluation where the consequence of policy intervention must be understood.

In this study, TFP is selected to measure productivity change rather than the annual FDH estimator, considering the dynamic year-to-year variations. Practically, the annual FDH scores can be calculated and used as panel data in the second stage of the analysis, however, such data series would be invalid given that fixed effects (i.e., the starting point for technical level by each state) are not controlled. However, TFP is not meant to address diffusion or technical progress over time since we did not add the constant c as shown in Equation (4) above to capture technical progress. Thus, this study focuses only on change in efficiency (or producers 'catching up' effects) rather than changes in frontier.

3. Methodology and data

This study aims to understand whether contracts enhance state highway service efficiency through two analytical stages. The first stage assigns an annual technical efficiency score for a state's highway output by calculating Malmquist's Total Function Productivity (TFP) index. In the second stage, the TFP index is regressed against highway construction contracts to understand the impact of contracts on spending efficiency.

Stage I: Total Function Productivity (TFP) index as an efficiency measurement tool.

Our study includes three output measurements: total state administered highway lane miles, the percentage of road mileage in good condition (i.e., without roughness), and total traffic flow. These metrics signify highway quantity output, quality output, and immediate highway outcomes in terms of reducing travel times for road users. These outputs are selected based on existing studies on state highways using the DEA method (Falah-Fini et al., 2009; Kurmapu, 2012), emphasizing outputs must directly relate to inputs and production processes, and should contain both quality and quantity dimensions (Kurmapu, 2012). Total state-owned lane miles, percentage of road mileage in good condition, and total traffic flows are directly related to highway production process and inputs. Two inputs used to calculate Malmquist's TFP index include total state highway outlays (for new projects) and total maintenance outlays (in constant dollar value, based year 2000). The former represents costs for new projects while the latter signifies costs for maintenance. The summary statistics for the data used in this stage are provided in the Appendix. All input and output data were derived from the Federal Highway Administration (2023).

Table 1. Summary statistics-tfp.

Observation	Mean	Standard Deviation	Minimum	Maximum
480	1.36	1.149	0.09957	6.6222

Table 2. Annual average TFP: 1998–2008.

Alabama	10.7%	Maine	2.7%	Ohio	1.3%
Arizona	−1.0%	Maryland	32.0%	Oklahoma	10.7%
Arkansas	13.8%	Massachusetts	8.8%	Oregon	3.5%
California	7.6%	Michigan	22.1%	Pennsylvania	−3.9%
Colorado	6.0%	Minnesota	3.5%	Rhode Island	−7.9%
Connecticut	4.3%	Mississippi	18.9%	South Carolina	14.6%
Delaware	−0.7%	Missouri	15.5%	South Dakota	−12.2%
Florida	−9.1%	Montana	1.5%	Tennessee	12.3%
Georgia	0.2%	Nebraska	13.7%	Texas	−15.3%
Idaho	7.7%	Nevada	−7.3%	Utah	18.4%
Illinois	−1.9%	New Hampshire	12.3%	Vermont	−9.7%
Indiana	−13.7%	New Jersey	10.4%	Virginia	49.4%
Iowa	−2.0%	New Mexico	−6.7%	Washington	17.1%
Kansas	21.0%	New York	9.4%	West Virginia	22.2%
Kentucky	1.9%	North Carolina	13.7%	Wisconsin	13.7%
Louisiana	4.8%	North Dakota	−24.6%	Wyoming	6.7%

Source: Authors' calculation.

Table 1 presents TFP summary statistics for the 48 states over the 9-year period ranging from 1998 to 2008 (the first year is omitted as the base year). As described above, holding constant for technical change, a TFP greater than one signifies that the total productivity is increasing; a TFP smaller than one suggests that the total productivity is decreasing, and a TFP equivalent to one suggests that the total productivity is the same.

Table 2 presents the annual average change for state highway productivity from 1998 to 2008. The complete dataset is available upon request due to space constraints. **Figure 1** below presents a pattern of the TFP statistics shown in **Table 1**.

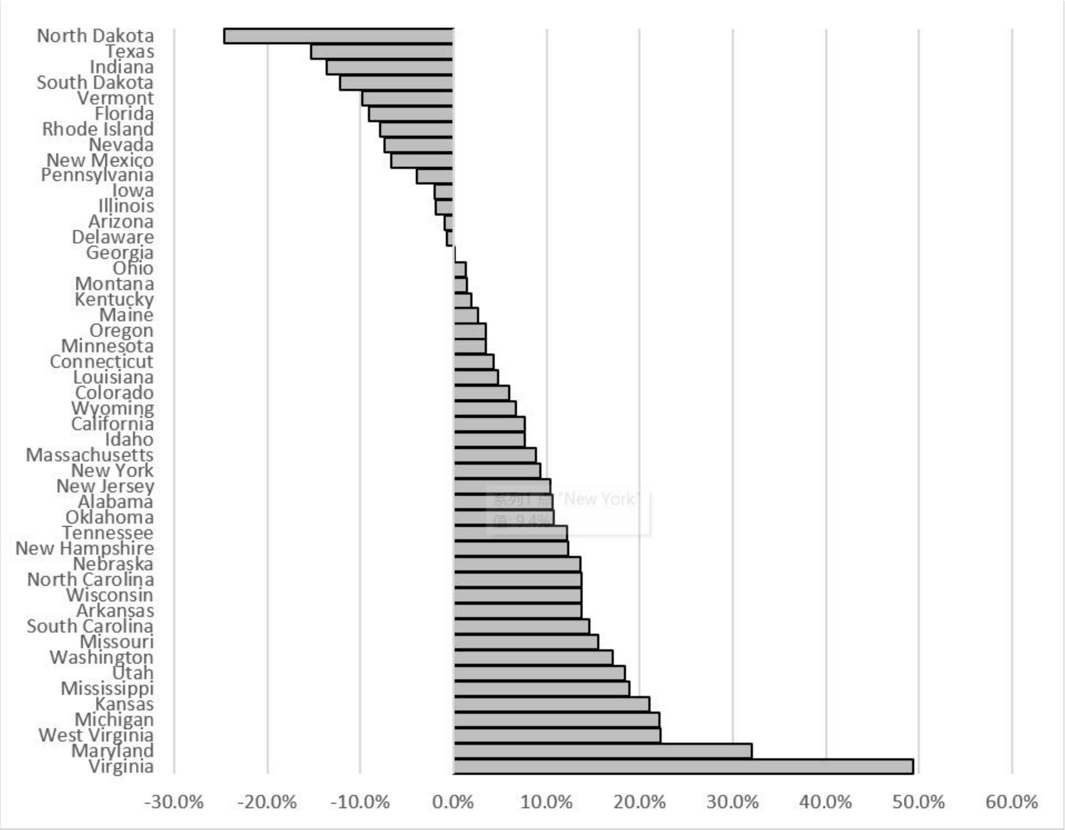

Figure 1. Nine-year productivity growth distribution.

Source: Authors' calculation.

Figure 1 depicts a relatively normal distribution of TFP annual average growth rates, showing no evidence of regional patterns. Two of the states with the lowest TFP growth rates are small states in the upper Great Plains region (North Dakota and South Dakota). However, other small Great Plains states such as Kansas and Nebraska rank among the top performers. Texas has one of the lowest TFP growth rates, while Oklahoma and Arkansas are in the top third.

Figure 1 also reveals that factors like partisan ideology, government structures (e.g., strong executive powers), and political values are unlikely to affect state highway productivity. For example, despite Texas and North Dakota being conservative states, their productivity is shrinking over the study period (−24.6% and −15.3% per year respectively) while Kansas and Oklahoma, also conservative, exhibit growth (21% and 10.7% per year respectively). For an executive power pattern, Rhode Island and New Hampshire, by constitutions, do not grant line-item veto to state governors (National Association of State Budget Officers, 2008). However, Rhode Island's productivity is decreasing while New Hampshire's is growing. Pennsylvania and Massachusetts by constitutions, grant the strongest gubernatorial veto by allowing line-item vetoes, item vetoes of appropriation, and item vetoes of selected words (National Association of State Budget Officers, 2008). However, Pennsylvania's productivity is shrinking while Massachusetts's is growing. **Figure 1** also shows that political cultures tend to not affect state productivity. For example, Vermont, Florida and Indiana have different political cultures categorized by Elazar (1966), yet all states face declining productivity. Thus, we argue that geographic location, state partisan ideology, and characteristics of state government structure such as executive power and political cultures are not relevant to state TFP values. By panel data definition, these variables are "time-invariant" which are meant to be picked up by such panel data analysis methods as TFP and SDPD.

Stage II: Statistical models to examine the impacts of highway construction contracts.

Productivity and efficiency both involve the input-output ratio. While efficiency is tied to the best possible production process, productivity focuses on this ratio's magnitude. Both terms are interchangeably used and can enhance each other (Dario and Simar, 2007). Since TFP is built based on FDH concepts adding a time dimension, the TFP indexes convey the concept of "total productivity" rather than "partial productivity" as FDH does. Partial productivity concerns a sole factor in production processes while total productivity concerns total factor (or global) productivity. Thus, we need an appropriate productivity theory to build the testing model.

The most widely used economic theory in academic literature is the Cobb–Douglas production function representing the relationship between the outputs and the combination of the factors (inputs) used for production. As extensively described in the previous section, the TFP depends on technical progress (i.e., scale economy and allocative efficiency) and catching up efficiency in production processes. Hence, the Cobb-Douglas production function is an appropriate base model for this study. Previous studies exploring efficiency factors (e.g., Inmaculada, et al., 2011; Turner et al., 2004), also use the Cobb-Douglas production function as the regression model.

To the authors' best knowledge, quantitative studies using econometric models to understand U.S. highway efficiency are scarce, creating a gap in literature that this study aims to address. While efficiency studies exist for local public schools (Ruggiero et al., 1995), their specific focus on variables like enrollment, teacher count, and salaries limits their applicability to state highways. The most useful efficiency study in the transportation field examined factors affecting North American container port productivity (Turner et al., 2004). The authors constructed an explanatory model using a Cobb-Douglas production function as the base theory, employing efficiency scores as the dependent variable. Then, the authors reviewed previously relevant studies in transportation (Chang, 1978; Kim and Sachish, 1986; Tongzon, 1995), establishing a model explaining the efficiency in transportation as shown in Equation (5) below.

$$\begin{aligned} &Efficiency_{i,t} \\ &= f(Production\ Structure_{i,t}, Service\ Demand_{i,t}, Situational\ Factors_{i,t}, Control\ Variables_{i,t}) \end{aligned} \quad (5)$$

In Turner et al.'s (2004) study, Production Structure included container port sizes, average container terminals, and dedicated terminal infrastructures. Service Demand involved mean vessel size and total vessel arrivals. Situational factors encompassed

Class I railroads serving seaports and draft of entering vessels at the 90th percentile. Control variables included quayside gantry cranes equipped for large vessels. Turner et al. (2004) used total terminal land dedicated to container operations, total quayside container gantry cranes and total container berth length as inputs in calculating the DEA score for port productivity. They used only one output, which was the total twenty-foot equivalent containers handled. The empirical results suggest that all variables except situational factors, draft of entering vessels at 90th percentile, and labor are statistically significant at a conventional level. Their findings suggest that for container ports, physical capital such as production structure (i.e., container port size, total terminals) are important to productivity while labor is not. This is reasonable given that the ports (and other transportation services) are capital intensive rather than labor intensive production processes.

Recent studies emphasized the importance of considering socio-economic variables to account for preferences and demands for services. Balaguer et al. (2012) examined municipal service efficiency in 1198 cities in Spain using DEA and FDH techniques. The outputs include tons of waste collected, number of road surface areas, number of public building surface areas, number of market surface areas, and population. The input variables include city government budgetary spending categories. By examining efficiency score distribution and conducting cluster analysis, the authors found that socio-economic variables such as population, income, and the amount of land do affect the efficiency level: high-income cities demand 30 percent more service than medium and low-income level cities. Similarly, Perez-Lopez et al. (2016) investigated the efficiency of waste service in 771 Spanish cities from 2007–2010. They empirically found that contracting improved efficiency scores for cities with populations exceeding 20,000.

Following Turner et al. (2004), our study examines production structure using total land areas (land), total state highway expenditure (K), and total number of civil engineers in the state (L). The state total land area indicates the production structure of the state highway production process. K and L are expected to positively relate to efficiency, unless other variables like technical progress alter the marginal rate of return for highway production. Data on state-owned lane miles as percent of statewide total (*planmile*) were derived from, Federal Highway Administration Statistics[1], while the total state highway expenditure (K) data came from Federal Highway Administration (2023) in various years. According to the Federal Highway Administration, total expenditure for state highway services includes capital outlay, maintenance, highway and traffic services, administration, highway law enforcement and safety, debt service, and intergovernmental payments. The total number of civil engineers in the state (L) is derived from Occupational Employment Statistics (OES) reported by the Bureau of Labor Statistics. This variable provided cost estimates for materials and labor to determine a project's economic feasibility. We collected statistics for the number of highway maintenance workers, but did not include in the model given that this labor classification does not require specialized training as do civil engineers; hence, it does not affect the efficiency[2].

Service demand is measured by daily vehicle miles travelled (DVMT), a primary metric used by the Federal Highway Administration to measure travel activity on national highways. The daily travel times 365 days (366 days for leap years) equals annual miles travelled. The data is derived from Federal Highway Administration (2023). Situational factors are measured by state highway agency-owned public road lane miles as a percent of statewide total lane miles (*planmile*) (Federal Highway Administration, 2023). Given that this study investigates the effect of contracting on highway productivity, the percent of construction employment is added into the model to control for the construction sector's size.

For control variables, we follow Balaguer et al. (2012) and Perez-Lopez et al. (2016) by including socio-economic variables like population and Gross Domestic Product. The dummy variables measure whether a state governor faces an election in the following year and the proportion of legislature seats facing election in the following year. As revealed by **Figure 1**, there is no discernible pattern suggesting that geographical location, state partisan ideology, or state government structure characteristics affect state highway productivity.

Based on the literature described above, the testing model is built based on a Cobb-Douglas production function augmented by four components including production structure, service demand, situation factors and control variables. Equation (6) presents the testing model,

$$\begin{aligned} TFP_{i,t} = {} & a + b_1 lnK_{i,t} + b_2 lnL_{i,t} + b_3 lnland_{i,t} + b_4 lnDVMT_{i,t} + b_5 planemile_{i,t} + b_6 pconstruct_{i,t} + b_7 PCC_{i,t} \\ & + b_8 PCCsmall_{i,t} + b_9 lnpop_{i,t} + b_{10} lngsp_{i,t} + b_{11} govpar_{i,t} + b_{12} legact_{i,t} \sum_{j-1}^{48} b13\, S_t \\ & + \sum_{k-1998}^{2008} b14\, T_t + \varepsilon_{i,t} \end{aligned} \tag{6}$$

where $TFP_{i,t}$ is efficiency index for highway production in state *i* at year *t*.

$lnK_{i,t}$ is log of total state highway expenditure in state *i* at year *t*.

$lnL_{i,t}$ is log of total number of civil engineers (including highway engineers) in state *i* at year *t*.

$lnland_{i,t}$ is log of total land areas in state *i* at year *t*.

$lnDMVT_{i,t}$ is log of annual daily mile vehicle travel (i.e., DMVT * 365 days or 366 days depend on years) in state *i* at year *t*.

$planmile_{i,t}$ is percent of state-owned highway lane mile to statewide total lane miles in state *i* at year *t*.

$pconstruct_{i,t}$ is percent of construction employment to total private non-farm employment in state *i* at year *t*.

$PCC_{i,t}$ is the percentage of construction contract in dollar value to total construction cost in state *i* at year *t*.

$PCC_{i,t} * small_{i,t}$ is the interactive variables PCC * dummy variable small-sized state in state *i* at year *t*.

$lnpop_{i,t}$ is log of total population in state *i* at year *t*.

$lngsp_{i,t}$ is log of total gross state product in state *i* at year *t*.

$gov_{i,t}$ is number of years left for state governor term in state *i* at year *t*.

$legact_{i,t}$ is proportion of upper chamber seats in state legislatures facing an election in current year in state *i* at year *t*.

S_t is state fixed effect, (incorporated by adding differenced values of the model's independent variables in System Dynamic Panel Data estimation)
T_t is time fixed effect.

The variables of interest for this study are the percentage of construction contracts in dollar value to total construction costs ($PCC_{i,t}$) and the interactive variable ($PCC \times small_{i,t}$). The $PCC_{i,t}$ is calculated by dividing the dollar value of construction contracts by the total state highway construction cost, multiplied by 100. The data for highway construction contracts in dollar value were derived from ARTBA (2014). According to ARTBA (2014), total construction contracts are measured by the dollar value that state DOT's disburse to the private highway construction contractors in each quarter of a year.

The total state highway construction cost data was derived from total state highway capital outlay and maintenance disbursement reported by Federal Highway Administration (2023) in various years. This data was used by highway policy research as an indicator for total state highway construction costs (Hartgen and Fields, 2016). According to Hartgen and Fields (2016, p. 41), "Capital" are funds intended to reconstruct or improve the system, whereas "maintenance" funds are those intended to preserve or repair the system. However, definitions for these categories can vary across states. Most states use private sector contracts to build and reconstruct the system, sometimes supplementing their own workforces for some projects. Most states also conduct maintenance largely with agency forces. Based on these definitions, the variability of $PCC_{i,t}$ depends on the level of major reconstruction and repairs, the sizes of the reconstruction or projects, and civil engineers' determination as to whether a project will be contracted based on cost estimation.

The interactive variable $PCC_{i,t} \times small_{i,t}$ was included to capture the effect of state size when contracts are implemented. To address interpretational challenges arising from two continuous variables interacting, we interact the continuous variable $PCC_{i,t}$ with the dummy variable for small population ($small_{i,t}$). A state was classified as small if its total population was 4,300,000 or less, as 4,300,000 is the median value (i.e., 50th percentile) in the dataset. Administrative costs in highway contracts exist since performance contracts require evaluation and monitoring by qualified civil engineers. This cost is fixed and can be relatively large regardless of the number of contracts states use.

Table 3 presents summary statistics. Data for state net land areas were derived from the Federal Highway Administration. State population, state Gross Domestic Product and percent of construction employment data were gathered from the Bureau of Economic Analysis. Political data including proportion of upper chamber seats up for election and governor party data were collected from Carl Klarner's State Legislative Partisanship and Codebook for State Elections, respectively[3].

Table 3. Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max

K: Total State Highway Expenditure ($1000)	480	1,981,961	1,924,543	203,625	15,500,000
L: Total number of Civil Engineer	476	4549	5802	300	38,530
Land: Total State Squared Mile	432	61,981	46,728	1,045	261,920
DMVT: Annual Daily Mile Vehicle Travel	480	105,246	99,497	2249	509,959
planemile: % of State-owned highway lane miles to statewide total lane mile	480	24.5	20.6	8.4	92.0
pconstruction: % of construction employment to total employment	477	6.4	1.0	4.2	10.2
PCC: percentage of construction contract in dollar value to total construction cost	480	9.6%	14.0%	0.1%	100.0%
PCC*small: the interactive variables PCC * dummy variable small-population sized (4.3 million)	480	2.2%	4%	0%	31.1%
Pop: Total number of population	480	5,958,731	6,459,633	491,780	37,000,000
GSP: Gross State Product ($billion)	480	244	290	18.9	1760
Gov: Dummy variable whether state governor faces term election in the next year	480	−0.1	0.99	−1	1
Legact: percent of state legislator facing new election in the current year (%)	480	33%	40%	0%	100%

4. Empirical results

As reviewed above, the two studies in which TFP is the model’s dependent variable (i.e., Inmaculada et al., 2011; Turner et al., 2004) use System Dynamic Panel Data (SDPD) to estimate the effect of total input factors on efficiency. According to Inmaculada et al. (2011), SDPD is the standard approach for estimating productivity growth due to two reasons. First, by nature, productivity growth has an inherent problem in that the observation at one point in time (i.e., TFP value in this study) is correlated with one in the following time point: serial correlation. Serial correlation yields biased estimators given that the data are not identically and independently distributed (Stock and Watson, 2001). SDPD[4] corrects it by adding a lagged dependent variable and serial correlation correction terms into the model (Stock and Watson, 2001). The serial correlation correction terms are built based on the value of autocorrelation detected by Durbin-Watson statistics. Second, growth data often exhibit endogeneity, where variables on both sides affect each other. By adding both terms the covariate between the dependent variable and the unobserved panel effect (fixed or random) can be controlled (Stock and Watson, 2001).

Endogeneity yields biased results since the errors are correlated with explanatory variables. SDPD corrects this by adding system estimators that use additional moment conditions to capture the changes in dependent variable from year to year. Like the Two-Stage Least Square method (2SLS), SDPD is a reduced form in which the lagged differenced values of the model’s variables are used as instrumental variables to estimate the effect of the independent variable on the dependent variable. The instrumental variables (i.e., the lagged difference value of the model’s variables) capture dynamic changes year by year.

Table 4. Estimated results for highway production efficiency.

Dependent Variable: Log of Total Function Productivity (lnTFP)

	Coef.	**Robust. Std. Err.**	***z***	***P* > |*z*|**
$lagged\ dependnet\ vraible, lnTFP_{i,t-1}$	−0.41	0.017	−24.21	0.000
$lnK_{i,t}$	0.21	0.103	2.00	0.046
$pconstruct_{i,t}$	−0.01	0.115	−0.11	0.909
$PCC_{i,t}$	4.23	0.363	11.68	0.000
$lnland_{i,t}$	0.42	0.260	1.62	0.105
$planemile_{i,t}$	0.02	0.034	0.48	0.630
$lnDMVT_{i,t}$	−1.04	1.533	−0.68	0.499
$lnL_{i,t}$	1.05	0.266	3.95	0.000
$lnpop_{i,t}$	−0.21	2.252	−0.10	0.924
$lngsp_{i,t}$	−0.04	1.783	−0.02	0.982
$legact_{i,t}$	0.07	0.038	1.96	0.050
$gov_{i,t}$	0.13	0.042	3.21	0.001
$PCC_{i,t} * small_{i,t}$	7.02	0.703	10.00	0.000
yr2	−0.31	0.411	−0.76	0.447
yr3	−0.09	0.393	−0.24	0.809
yr4	−0.18	0.393	−0.47	0.639
yr5	−0.12	0.418	−0.30	0.765
yr6	−0.10	0.415	−0.23	0.817
yr9	0.07	0.090	0.73	0.466
yr10	−0.05	0.105	−0.51	0.612
Constant	2.07	20.344	0.10	0.919

Model is estimated by System Dynamic Panel Data Estimation

Number of observations: 381, Group variable: state id, number of groups: 48

Time varying variable: year, Entity variable: state, Number of Instruments: 51

Wald Chi^2 (19) = 21273.81, Probability > Chi^2 (20) = 0.0000

Pseudo $R^2 = 0.4792$

* Year 7 and 8 were omitted due to multicollinearity.

Due to autocorrelation and covariate between dependent variable and unobserved panel-level effects, system dynamic panel data estimation (SDPD) was used to estimate the model above. In SDPD, *p* lags were used as instrumental variables to estimate dynamic effects in differenced value equations. The number of lags used as instrumental variable to estimate differenced equation is 3. One-year lag in level equation is included to control for serial correlation in reduced from to control for serial correlation. This appropriate lag length was chosen by serial correlation text statistics. See statistics testing results for serial correlation and overidentification for the model instruments in **Tables A2 and **A3**, respectively, in Appendix.

Our empirical model employs TFP as a dependent variable in the productivity model. We use Cobb-Douglas production function as an underlying assumption. Equation (8) was estimated by SDPD. **Table 4** presents empirical results using SDPD to control for serial correlation and endogeneity. The instrumental variables include three lags of the differenced values for dependent and independent variables. The choice of the three-year lag length for the differenced and level equations in SDPD was determined by the F-statistics and partial autocorrelation function (PCF) (Stock and Watson, 2001). As shown in **Table A2** of the Appendix, the Arellano-Bond test for zero autocorrelation suggests that there is no serial correlation when lag 3 is added into the model. As also shown in **Table A3** in the Appendix, the Sargan test suggests that the instrumental variables are valid for the reduced form.

As mentioned previously, the TFP index is calculated to capture only efficiency catching-up by state highway producers and does not capture technical progress since we did not add a cost constant into the time analysis. The first reason to exclude technical progress in this analysis is that we do not have valid and reliable highway cost data across 48 states. Another reason is that we take an incremental approach, rather than a holistic approach, in building knowledge of highway efficiency. Given TFP's inability to capture technical progress or "diffusion", we did not use the model to capture the "growth curve" or growth effect as suggested by Hoffman (2016). However, we follow Hoffman's (2016) suggestion by estimating the random coefficients of time depicted in **Table 4**. As seen in **Table 4**, all random coefficients for time diffusions are not statistically significant at a conventional level, confirming that the TFP in this study does not mean to address diffusion.

Table 4 highlights the coefficients for the variables of interest: the PCC (4.2) and PCC*small (7.0), both of which are strongly and statistically significant at the 0.01 level. For every one percent increase in contracting value to total construction cost, the performance efficiency index increases by 4.2 percent, all else equal. The finding confirms Savas (2000), Kettl (1993), Osborne and Gaebler (1992), Owen (1998), and Donahue's (1989) observation: contracting out enhances performance efficiency in highway construction by optimizing production size in alignment with workload and task complexity. The significant coefficient of PCC*small suggests that contracts yield more efficiency in small states—that is, for a state with a population below 4.3 million, the highway efficiency index increases by seven points in addition to 4.2 points for contracts. This result implies that in small states, the administrative cost for civil engineers monitoring contracted projects is less than fixed personnel labor costs for in-house supervisors. Furthermore, small states tend to achieve more transactional cost savings through contracts compared to larger states.

As shown in **Table 4**, for production structure variables, the coefficients for K and L are statistically significant at the 0.01 level, while Land's coefficient remains insignificant. Every one percent increase in capital (K) corresponds to a 0.20 percent increase in highway efficiency, while a one percent increase in civil engineers (L) leads to about a 1.15 percent increase in highway efficiency. This finding reveals that technical capacity and capital are important in highway production processes. The coefficient for the service demand variable (DMVT) and situational variables (*pcon* and *planemile*) are insignificant at the conventional level although they are exhibiting expected signs. These variables were strongly and statistically significant when the interactive variable PCC*small was excluded, suggesting that in highway performance, efficiency depends mostly on production size rather than production situations. The coefficients for state government structure variables were statistically significant at the 0.05 level and signs are as anticipated. When a state governor faces election in the following year, highway performance efficiency increases at about seven percent. For every one percent increase in state legislator seats facing new election, highway performance efficiency increases at about 1.3 percent.

5. Conclusion

This study examines the effect of state highway construction contracts on state highway efficiency. The main hypothesis is that in highway construction, contracts tend to enhance productivity. This is because contractors can help a state achieve efficiency through optimizing the size of public works projects amid the high demands and task complexity in highway production. The empirical results were derived through two stages of analysis. In the first stage, the annual TFP for each state was calculated through Malmquist's Total Production Function method, reflecting performance efficiency. In the second stage, the TFP statistics were regressed against the percent of construction contract in dollar value to total state highway construction costs, controlling for production structure, service demands, situational factors, and state government political variables. The empirical results suggest that the size of the contracts, measured by total construction cost, enhances efficiency. This implies that optimizing project size leads to efficiency gains through cost savings. The results also suggest that small states tend to obtain greater efficiency through highway construction contracts.

The results contribute to theory and practice in two ways. First, the findings validate existing public productivity literature by emphasizing that contracts can help service providers achieve efficiency, particularly in a large-scale, complex production process like state highway construction programs, which face increasing demands from year to year and can be monitored by service providers. From a practical standpoint, the significance of the percent of contracts to total construction costs signifies that major repair and new construction projects are more suitable candidates for contracting than repair projects, all else equal.

This study is not without limitations. Unlike cross sectional DEA, the TFP in this study does not capture efficiency changes due to technical progress, which requires annual state cost data. The results in this study reveal only a dimension of efficiency due to operational catching-up of state highway producers. Future studies could replicate this study by integrating cost data and exploring technical progress or growth diffusion to add incremental knowledge in state productivity literature.

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Notes

1. See https://www.fhwa.dot.gov/policyinformation/statistics/2014/
2. At the time of estimation, we did try to include highway maintenance workers in the model. As theoretically expected, this variable is not statistically significant given that it does not provide value-added to the technical progress. To preserve one degree of freedom, we dropped this variable.

[3] http://klarnerpolitics.com/kp-dataset-page.html

[4] Please see Arellano and Bover (1995) and Blundell and Bond (1998) for extensive backgrounds of SDPD modeling.

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Appendix

Table A1. Summary Statistics for TFP Index.

	Mean	**Std. Dev.**	**Min.**	**Max.**	**Obs.**
Inputs					
Capital Outlay	965,154	880,027	76,999	6,734,868	528
Real Maintenance Outlay	188,830	202,077	2,191	1,292,524	528
Outputs					
State Urban and Rural Mile by ownership	15,973	17,235	1,102	80,067	528
Urban and Rural Service Flow	19,996	13,640	1,444	83,270	528
Percent of Road without Roughness	38.24	30.64	16.1	90.4	528

* $1000, base year 2000, adjusted by Producer Price Index derived from Bureau of Economic Analysis (2013).

Table A2. Serial correlation test results.

Arellano-Bond test for zero autocorrelation in first-differenced errors		
Ho: No autocorrelation		
Lag Order	*Z*-Value	*P*-Value
1	−4.5468	0.0000
2	−2.3998	0.0164
3	0.8161	0.4144

Table A3. Overidentification test results for instrumental variables (Lagged variables).

Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
Chi^2 (30) = 35.6629
Prob > Chi^2 = 0.2193