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Policy lessons for regulating public–private partnership tolling schemes in urban environments

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ABSTRACT

Public–private partnerships (P3s) are likely to impact entire transportation systems in fundamental ways. However, few studies have examined the potential impact of P3s on large-scale transportation networks. These studies have focused on modeling rather than on policy analysis. The literature thus does not offer guidance for designing and administering P3s to improve transportation system performance while maintaining profitability. Using Fresno, California's transportation network as a laboratory, we consider the effects of alternative P3 tolling approaches on profit maximization and system performance optimization at full urban transportation network scale. Based on system modeling results, we offer the following recommendations for policy makers to design and promote successful P3s in urban settings: (i) to promote a profitable and a socially beneficial system, toll rates should be set examining both profit-maximizing and system-optimal rates; (ii) even though tolls (i.e., higher travel costs) on a few roads help reduce travel demand they may, counter-intuitively, lead to higher total travel cost for the overall transportation system because of users' decision to travel longer distances to avoid tolls, especially when high toll rates are applied; (iii) lower limit(s) on tolls (in addition to upper limits) may be required to enforce system-optimal tolling and avoid undercutting by private owners; (iv) a variable tolling approach (i.e., temporally- and spatially-varying tolls) significantly reduces congestion and increases profits relative to flat tolls; and (v) public officials should provide a comprehensive plan regarding past, current, and future P3 projects along with a detailed system-wide impact analysis to promote a more sustainable transportation system.

1. Introduction

Sharp declines in funding from traditional sources combined with large, ongoing investment needs suggest that a major change in transportation policy is required. The main transportation infrastructure funding source—fuel tax revenue—is falling as vehicular fuel efficiency rises and as annual vehicle miles travelled in the United States declines (American Society of Civil Engineers, ASCE, 2013). Many segments of the U.S. transportation are old and in poor condition (The Road Information Project TRIP, 2011). Moreover, fuel taxes cannot provide the flexibility necessary to incentivize efficient use of transportation resources (Kim et al., 2008; Rouhani, 2009). Public–private partnerships (P3s) have been viewed by many experts as an alternative mechanism that can help address such problems. To tackle the intensifying challenges faced by the U.S. transportation system, both the public and private sectors should search for more innovative yet measured P3 models and accompanying legislation (Zhang, 2005; Chung et al., 2010; de Jong et al., 2010).

Our knowledge of P3's system-wide effects is limited. Generally, previous research has relied on a project-specific approach. Overall P3 success, however, hinges on more than project-specific financial analysis. Therefore, it is critical to develop better insights into the range and types of regulatory processes that successfully support P3s in transportation networks (see e.g., Chen and Subprasom, 2007; Rouhani and Niemeier, 2011; Rouhani, 2012).

Several studies have examined private participation in large-scale transport networks. Zhang and Levinson (2009) evaluated short-run and long-run network performance under alternative ownership structures (private/public and centralized/decentralized). Zhang (2008) analyzed the combination of pricing, investment, and ownership to study the welfare impacts of road privatization on a large-scale network (the Twin Cities). Dimitriou et al. (2009) developed a game-theoretic formulation for the joint

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optimization of capacity investments and toll charges, examining practical issues such as the regulation of tolls on privately-operated highways. Rouhani et al. (2013) used demand analysis and game theory concepts to model the effects of including several concession projects on a number of system performance measures.

Existing studies have focused either on model development (see above) or on real-life P3 projects analysis only without a systems perspective (e.g., Evenhuis and Vickerman, 2010). Key policy insights about how the implementation of P3 projects affects a transportation system as a whole and how the P3 contracts should be regulated in urban transportation systems are absent in the literature. We attempt to fill that gap and generate policy recommendations by simulating recurrent traffic congestion under various P3 approaches, using the Fresno, California road network as a mid-size urban system case study. We focus mainly on regulating P3s that grant a private developer (usually a consortium of firms) the right to collect tolls from an existing facility under a long-term concession contract. Public-sector project sponsors retain monitoring and enforcement responsibilities (Reason Foundation, 2009).

Our goal is to offer insights into the following fundamental issues: (i) the distinction between profit/revenue-maximizing and system performance-optimizing road pricing; (ii) the merits of providing spatially- and temporally-variable tolling as compared to flat-rate tolling; (iii) the impact of toll collection costs; and (iv) the effect of P3s on system-wide travel costs, including emissions and fuel consumption. We conclude by suggesting a list of major factors that the public sector should take into account when planning for the use of P3s on toll roads in an urban setting.

2. Methodology and case study

2.1. Modeling

The basic mathematical approaches borrow from our previous studies, including modified traffic assignment (Rouhani and Niemeier, 2011), profit maximization (Rouhani et al., 2013), general system cost minimization (Rouhani and Niemeier, 2014a), and spatial variation in tolls (Rouhani and Niemeier, 2014b). To model different problems, we employ a bi-level programming framework. At the higher level, policy makers/private operators pursue two basic objectives for system operation: transportation system performance optimization and toll-profit maximization. At the lower level, travelers react to the application of various toll schedules and modify their travel choices.

We provide a brief description of the two major higher-level problems we consider: (1) the transportation system general cost minimization (SGCM) problem in order to optimize system performance; and (2) the profit-maximization problem (PMP). The SGCM problem minimizes a monetary combination of total travel time, fuel consumption, and emissions costs over a transportation system, excluding toll costs since tolls are transfers between two groups and do not affect system performance. SGCM accounts for the social welfare loss resulting from reduced travel demand as well (Rouhani and Niemeier, 2011). The problem's decision variables are the toll rate on each of the candidate roads. Policy makers might use the resulting system-optimal rates from SGCM as the basis for limiting private firm's toll rates.

The PMP simulates a different problem: private firms solve for the profit (or revenue minus toll collection cost) maximization problem and find the corresponding optimal toll rate. However, the toll rate might be constrained (i.e., capped) by P3 contracts, which could affect the optimal toll rate and the optimal profit from toll collection. To account for the impact of toll collection costs, we solve two versions of the PMP problem: (1) revenue maximization by ignoring toll collection costs; and (2) profit maximization taking toll collection costs into account.

An important extension of the PMP and SGCM models, called a "spatial variation model," allows tolls to vary across different segments of the tolled road (Rouhani and Niemeier, 2014b). Spatial variation in tolls can induce a more-profitable or a system-improving efficient traffic flow pattern. The problems discussed above all use a modified user-equilibrium (UE) model as the underlying (lower-level) model to simulate users' behavior. The modified UE assumes that users account for general costs of travel rather than travel time only. The modified model updates origin/destination (O/D) demand iteratively, considering the updated (higher) general costs of travel.[1]

2.2. Assumptions

For simplicity and because of modeling constraints, we make several basic assumptions. We have divided our assumptions into three categories

2.3. Transportation planning model

(1) The transportation planning model is a static deterministic user-equilibrium model (Sheffi, 1984);
(2) neither the city of Fresno nor its planning model has a strong public transportation system. Therefore, we do not consider potential switching to a public transportation mode; and
(3) the planning model is a single-user equilibrium model. Because of variations in the value of time (VOT) for different user classes, a single-user equilibrium model is inadequate for a comprehensive analysis of impacts across user classes. However, city-size models generally do not cover multi-class user equilibrium features, as for our transportation planning model. Hence, we focus mainly on the aggregate impacts on average users.

2.4. General travel costs

(1) Using a slightly lower rate than the average wage of $16.79 per hour for Fresno (Schrank et al., 2012), we assume that an average user values time at $14/hour. Considering the load factor of 1.4 persons/vehicle, the value of time for each vehicle is estimated at $20/hour (14 × 1.4);
(2) based on California Air Resources Board's (CARB's) EMFAC (2011) model for mobile emissions inventory calculation, the emission factors are calculated using the VMT-weighted averages for different vehicle classes at different speeds (Rouhani and Gao, 2014); and
(3) to calculate transportation system emissions and fuel costs, we use the following parameters: $25/ton of CO_2, $250/ton of CO, $7000/ton of NO_x, $3000/ton of TOG, $30,000/ton of PM_{10}, $300,000/ton of $PM_{2.5}$.[2]

2.5. Tolling

(1) For flat tolls, tolling agencies apply a constant mileage-based toll rate on all toll road segments. For variable tolls, the toll rate is different for each road segment (spatial variation) and/

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[1] See Appendix for detailed information about the mathematical models used in this study.

[2] These criteria-pollutant health-related cost rates are the average estimates of the following studies: Wang et al. (1994), McCubbin and Delucchi (1999), and AEA Technology Environment (2005). We also assume $4 per gallon of gasoline.