SOCIAL WELFARE ANALYSIS FOR ALTERNATIVE INVESTMENT PUBLIC-PRIVATE PARTNERSHIP APPROACHES

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ABSTRACT

Policy makers often evaluate public-private partnerships (P3) projects using Value for Money (VfM) analysis. However, a P3 project's impact on overall social welfare provides a more comprehensive evaluation criterion. Apart from several theoretical studies, a detailed social welfare analysis that includes all major P3 project stakeholders (residents, users, government, and the private sector) is lacking in the transportation literature. We offer a framework estimating the benefits and costs of using alternative Investment P3 (IP3) approaches. An IP3 returns a significant portion of the value created by road pricing back to the citizen-owners of a newly priced transportation facility in an urban transportation system. A major policy insight from our study is that system-optimal tolling scenarios favor average users, but government – and consequently taxpayers – should pay for costly tolling systems. In contrast, scenarios allowing unlimited profit maximization raise substantial profits for government, citizen-owners, and the private sector, but the average user is worse off. From a social welfare perspective, one should search for a Pareto-optimal solution where all stakeholders are better-off. Our estimates indicate that such a solution can be achieved through a mixed private and public operating scheme. This solution provides the highest social welfare unless the weight of users is substantially lower or the weight of residents is dramatically higher than other stakeholders' weights.

Keywords: *Investment public private partnerships; Social welfare analysis; Residents; Users; Urban transportation systems.*

1. Introduction

Interest in the question of which type of transportation facilities, business models, and ownership structures underpin successful public-private partnerships (P3s) is growing among both public and private sector participants. A key part of the answer lies in exploring new and innovative policy approaches that capture the potential of P3s to help address endemic funding, project delivery, and quality of service problems.

Geddes and Nentchev (2013) propose a novel Investment–P3 (IP3) approach to help address such concerns. In an IP3, a portion of the wealth generated by leasing existing (un-priced) transportation facilities is preserved in a public permanent fund; new wealth is generated by pricing these facilities. At the beginning of the process, the public sector announces a request for qualification (RFQ) to attract and screen qualified bidders. The winning bidder is then selected based on the maximum concession payment offered for the facility over a pre-determined period of time. Such bidding ensures the largest upfront payment by private partners. Concession payments are used to capitalize a public permanent fund. The use of a permanent fund that preserves the largest fraction of concession lease proceeds in perpetuity mirrors the successful Alaska permanent fund model, which preserves oil lease income (Olson and O'Brien, 1990). Annual dividend payments from the fund's investment income are then distributed to all households (citizens) in the relevant jurisdiction. As the ultimate owners of transportation infrastructure, such households have a claim on the value transportation infrastructure creates.

Using Geddes and Nentchev's approach (2013), IP3 offers several advantages over common P3 concessions. First, redistribution of profits (the dividends) from the permanent fund investment income to residents ameliorates concerns regarding potential misuse of lease proceeds, and reduces opportunities for using large cash flows from concessions to fund projects that offer short-term political appeal but may not enhance long-run social welfare. Cash from annual dividends generates greater support from citizens than does the mandated spending associated with many real-life P3 projects, which may not generate benefits for all citizens. For example, some proceeds from the Chicago Skyway concession lease were used for non-transportation purposes (Buxbaum and Ortiz, 2007).

Second, public involvement through direct redistribution of transportation infrastructure income encourages residents to take greater interest the maintenance and operation of their infrastructure. It can thus create true citizen stakeholder-ship in transportation infrastructure while increasing awareness of efficient use of transportation infrastructure. Third, an IP3 enhances income equality by providing additional income through regular dividend payments and jobs created by the new organizations. As demonstrated by economic theory, citizens receive greater utility from the added goods they can buy with cash dividend payments than from payments earmarked for a specific purpose. This increases support for the adoption of an IP3 approach and the accompanying road pricing. Fourth, an IP3 approach recognizes explicitly the property rights that citizen-owners currently possess in transportation infrastructure and results in the true value of transportation infrastructure assets being revealed through competitive bidding.

Finally, private sector participation incentivizes more efficient provision of transportation systems through life-cycle maintenance and lower toll collection costs. However, the private sector might have incentives to provide a lower quality service with a short-term contract (De Bettignies and Ross, 2004). Also, transfer of certain risks inherent in infrastructure projects onto private investors is a frequently recognized benefit of private participation (Vining and Boardman, 2008).

To measure the benefits and costs of an IP3 (and, in general, any project), we first determine the criterion for appraising the approach. The relevant criterion should determine whether or not the approach serves the overall public interest. In practice, government agencies evaluate P3 projects using Value for Money (VfM) analysis (Yuan et al., 2009) although the most appropriate evaluation criterion is overall social welfare (Boardman and Vining, 2012). In fact, a VfM analysis might lead to a reduction in social value rather than its enhancement since it accounts only for the costs of project development, not its benefits. VfM studies also often use inappropriately high discount rates (Boardman et al., 2010). To provide a detailed social welfare analysis for evaluating the IP3 approach, major stakeholders' gains and losses from using a P3 project(s) should be compared to the gains and losses from a traditional (public) approach of providing the same infrastructure or service.

Theoretical modeling of social welfare from private road pricing has analyzed the effects of duopoly and monopoly structures (Zhang, 2008; Winston and Yan, 2011; Rouhani and Niemeier, 2011), the effects of various assumptions about drivers' value of time (Yang and Zhang, 2002), the effects of traffic diversion to secondary roads (Swan and Belzer, 2010), and impacts of alternative privatization structures and regulations (Yang and Meng, 2000; Tan et al. 2010; Zhang and Yusufzyanova, 2012; Rouhani et al., 2013*a*). Such studies have focused mainly on system travel time on a few selected roads only. None have developed detailed analysis to evaluate the incorporation of a range of welfare components in implementing P3 projects. Existing studies also lack a much-needed general framework for social welfare analysis to identify effects on different P3 stakeholder groups.

In the congestion pricing (CP) context, several studies provide detailed frameworks to evaluate the social welfare impacts of CP schemes. Parry and Bento (2002) analysed the interactions between direct peak-period congestion pricing and "second best" factors, including congestion on un-priced routes, accident and pollution externalities, suboptimal transit pricing, and gasoline taxes. They found that the welfare loss resulting from "second best" interactions is comparable to their welfare gain. In another study, Safirova et al. (2004) examined the welfare effects of various road pricing schemes for the Washington, DC Metropolitan area. The major factors in their analysis were changes in travel time and tolls paid. Generally, these social welfare studies impose strong assumptions regarding implementation of the same toll rates on all roads and exclusion of externalities other than travel time-based congestion.

Moreover, social welfare studies in the urban transportation area do not fully consider proper boundaries for evaluating each policy scheme. Induced activities outside schemes' narrow boundaries could dramatically impact social welfare analyses (Zegras, 2007). In contrast, it is nearly impossible to fully capture welfare effects when using very broad boundaries. Nevertheless, we demonstrate that one can capture the major effects of the IP3 approach within urban cities' boundaries. Our approach estimates important and complex interrelations between different components of an urban transportation system and between different stakeholders within an IP3 approach.

We thus focus on developing a general social welfare analysis framework that includes major stakeholders within an IP3 approach. We describe the modeling required for evaluating an IP3 scheme in an urban transportation context, and estimate the social welfare change of implementing IP3 alternatives for a major urban city: Fresno, California. Although our focus is on the IP3 approach, most of our modeling framework can be generalized to other P3 models, such as greenfield projects, and to similar tolling (pricing) schemes.

2. Methodology

2.1. *Benchmark modeling*

A standard transportation planning model for Fresno serves as the benchmark model. We extend that model to simulate the behavior of transportation users under different IP3 and tolling schemes. Figure 1 shows the major models (problems) considered here. At the highest level, policy makers employ two basic objective functions for transportation system operation: transportation system cost minimization and toll profit maximization (Rouhani et al., 2013*b*), which corresponds to public and private road operation. The system cost minimization problem minimizes a monetary combination of total travel time, fuel consumption, and emissions costs over a transportation system with toll rates (τ_{ij}'s) as the decision variable, similar to the second-best pricing problem in some studies (e.g., Verhoef, 2007). This is an important approach because policy makers might use system-optimal rates as the basis for capping toll rates set by private concessioners. The system cost minimization problem is: (1)

$$\underset{\tau_{ij}}{Min} \sum_{i-j} \left(t_{ij}\left(x_{ij}^*\right). x_{ij}^*\right) + \sum_{k} \sum_{i-j} \gamma_k . \lambda_k \left(\frac{L_{ij}}{t_{ij}\left(x_{ij}^*\right)}\right). L_{ij}. x_{ij}^*$$

where x_{ij}^*, $t_{ij}\left(x_{ij}^*\right)$, γ_k, and λ_k are the user equilibrium flows, travel time functions for each link *i-j*, price of emissions and fuel in terms of time, and emissions factors in terms of speed, respectively. The first term is the total travel time, while the second is the total fuel consumption and emissions cost.

We also address another problem: private firms solve for the profit, revenue ($\tau_{ij}. x_{ij}^*(\bar{\tau})$) minus cost ($CF_{n,ij}(\bar{\tau})$), maximization problem to determine the optimal toll rate. However, toll rates may be capped as required by P3 contracts, which can affect the optimal toll rate and thus realized profit:

$$Max\ profit)\ \ \underset{\tau_{ij}}{Max}\ \pi_n = \sum_{(i,j)\in F_n} \tau_{ij}. x_{ij}^*(\bar{\tau}) - CF_{n,ij}(\bar{\tau}) \tag{2}$$

$$s.t.\ \tau_{ij} \le \tau_{ij} \tag{3}$$

where $\bar{\tau}$ is the vector of tolls comprised of τ_{ij}'s – tolls on each link *(i,j)* – which are capped by τ_{ij}'s[1].

In addition to these two basic models, we employ a spatial variation model, which is an important extension of the two basic models. This extension allows the toll rate to vary on different

[1] It can be shown mathematically that profit maximization and cost minimization problems result in the same solution. However, in our study, profit maximization problem maximizes the profits from toll collection on each road (or several roads for a monopolist), but the system cost minimization minimizes the transportation system travel costs (total travel time, total fuel consumption, and total emissions from the whole system) excluding toll costs. These two problems are different in their objective functions' general form and also in the facilities with which they are concerned (a road under the profit maximization versus a transportation system as a whole under the system cost minimization).

segments of the toll road to increase profit or to reduce congestion (Rouhani and Niemeier, 2013); τ_{ij}'s are different on a road. In fact, public and private officials adopt different toll rates on different links (or segments) of the road so that a more efficient, or profitable, traffic flow pattern can be reached.

The profit maximization model can also be extended by considering more than one profit-maximizing firm. This more complex model must make an assumption about firm interactions. We assume that non-cooperative behavior considering the Bertrand-Nash (B-N) equilibrium prevails (Rouhani et al., 2013*a*). This means that each firm (r) develops a response function based on its first-order conditions and determines its own toll rate based on the best response to other firms (s's) toll rates ($\bar{\tau}_{lm}$'s):

$$F.O. \rightarrow \tau_{ij}^{*} = f(\bar{\tau}_{lm}), \qquad \forall\,(i,j) \in F_r\ ,(l,m) \in\ F_s\,, s \neq r \tag{4}$$

The above models all use a modified version of the user equilibrium (UE) problem to determine users' choice in reaction to the various toll schedules applied. The modified UE assumes that the general cost of travel (tolls + time) drives users' choice instead of time only, and that origin/destination (O/D) demand is iteratively updated (reduced) considering the new (higher) general costs of travel, which includes a monetary combination of time and tolls for each O/D. The output of the modified UE problem is an equilibrium traffic flow pattern, which will be used to determine system travel costs (time, emissions, and fuel consumption), and toll system profits and costs. For detailed information about the models employed in this study, see (Rouhani and Niemeier, 2011; Rouhani and Niemeier, 2013; Rouhani et al., 2013*a* and *b*).

Fig. 1. General modeling framework.

2.2. *Social welfare analysis framework*

Suppose government considers whether or not to implement tolling on a transportation facility and what type of tolling system (public versus private-IP3) to use. The social welfare gain or loss from those decisions should be compared to the public sector alternative (PSA). In general, total social welfare change is the sum of the change in consumer surplus, the change in producer surplus, the change in government surplus, and the change in employee surplus. All components should be measured in present value terms (Boardman and Vining, 2010). A P3 project should be implemented when it improves total social welfare relative to the PSA.

Under an IP3, consumer and producer surplus are the welfare of transportation system users and private sector profits, respectively. Employee surplus can be measured by new salaries paid to the toll collection agency employees (a portion of toll collection costs). However, the transition from a public system to a private system may entail lower wages for employees since the private sector attempts to minimize costs (De Bettignies and Ross, 2004). Government surplus is realized from its assigned share of concession payments. In addition to these commonly used components, an IP3 social welfare analysis includes a term for the welfare of residents, or the citizen-owners, of the infrastructure. Although residents can also be users of transportation systems, but with different levels of usage, the differentiation between residents and users provides the information required for a more in-depth social welfare analysis. We assume a regional equilibrium for IP3 welfare analysis, in which the benefits and costs to those outside urban boundaries will not be counted.

Finally, the welfare of stakeholders under an IP3 approach should be compared to the no-tolling alternative (NTA) or the do-nothing case. The total social welfare change from an IP3 (ΔW, usually in net present value) can be written as:

$$\Delta W_{IP3-NTA} = \delta_U . \Delta UW_{IP3-NTA} + \delta_P . \Delta PW_{IP3-NTA} + \delta_G . \Delta GW_{IP3-NTA} + \delta_E . \Delta EW_{IP3-NTA} + \delta_R . \Delta RW_{IP3-NTA} \quad (5)$$

where ΔUW is the users' welfare change, ΔPW is the private sector's welfare change, ΔGW is the government's welfare change, ΔEW is the employees' welfare change, and ΔRW is the resident's welfare change. The parameters $\delta_U, \delta_P, \delta_G, \delta_E,$ and δ_R are the welfare weights. These parameters should be set equal to one based on the allocative efficiency criterion (Weimer and Vining, 2009) when conducting a normative evaluation. One critical decision is which group of stakeholders should enter the analysis, and thus whose benefits and costs should be counted. For example, users from outside the region might not have a standing, their benefits and costs might not be considered, in social welfare analysis specific to a region (Boardman and Vining, 2012).

Figure 2 categorizes the main factors that affect the welfare of each stakeholder type when applying any tolling arrangement in an urban environment. Users' welfare change is the sum of (1) the average amount of tolls paid by users; (2) the change in private travel costs (time and fuel), other than tolls, since the transportation system can become more (or less) efficient as a result of the applied toll scheme (Barr, 2004); and (3) the decrease in users' welfare because of the induced change in their travel behavior which creates disutility, e.g., some users might decide not to travel or to take public transportation because of the higher travel costs (tolls). In addition, users can benefit from improvements in transportation systems resulting from more funds available to the public sector. However, such benefits are difficult to estimate and might be negligible for an IP3 that assigns most of the toll profits to residents, rather than spending it directly on transportation infrastructure. Therefore, we do not consider such improvements in our analysis.

Fig. 2. Social welfare factors for each stakeholder type.

The private sector is assumed to maximize profit only (based on toll revenues minus toll collection costs). The private sector's profits are determined by the share of profits they would receive (or toll profits minus how much the private sector must pay to the public sector) and by the travel demand risk. The government's welfare change is from the profits of publicly-tolled roads (which could be negative since toll collection costs are high in urban settings with many entrance-exit points), and their share out of the profits of P3-tolled roads. Finally residents' welfare change can be measured by (1) dividends paid to each citizen (household) of the region out of the permanent fund, and (2) the change in the criteria pollutant and the CO_2 emissions level resulting from changes in transportation system performance. In addition, residents could be better-off by improvements in the urban system since profits from P3 projects could be used for improving their urban environment without improving the transportation system. However, we assume that profits would not be spent on urban system improvements.

The inclusion of toll revenues (profits) in our social welfare analysis contradicts what many road pricing studies have assumed (e.g., see Prud'homme and Bocarejo (2005)). According to those studies, toll revenues (or profits) are transfers of money from one group to another and therefore should not be a part of social welfare analysis. This simplified assumption seems defective for two reasons. First, the weights of different stakeholders (users versus residents) might be different, and e.g., the benefits to residents (through dividend payments from tolling profits) might be preferable to the costs to users (based on the amount of toll paid). Second, the benefits and costs of users from outside of the region (the amount of tolls they pay) might not be counted.

Toll collection costs and their effects on employee surplus should be considered in our analysis for the same reasons. We omit employee surplus resulting from toll collection costs because: (1) part of the toll collection costs are used for capital cost and operating costs other than payments to employees and should not be considered in the employee surplus; and (2) the employees' surplus (from tolling costs) should be compared to other sources of transportation finance (taxes) since higher spending on tolls could result in lower taxes paid.

Finally, our analysis only focuses on average effects on all stakeholders. Welfare effects are not homogenous across different groups of users, for example. Some users might pay more tolls and waste more time and fuel because of driving on more-congested roads than before while other users might pay no tolls and benefit from better system performance on specific parts of the transportation system that they use more. A more detailed analysis on different users groups (potentially a zonal analysis) is required to address such equity implications of an IP3 scheme.

2.3. *Assumptions*

In general, each model's limitations and assumptions are important in analyzing the study's results and policy insights. The major assumptions for our analysis are as follows:

- The Fresno transportation planning model is a static, deterministic, single-user equilibrium model (Sheffi, 1984). Since we incorporate an uncertain future, real-time prices and real-time demand analysis are not of our interest. Although a multi-user equilibrium is required for analyzing tolling schemes, large-scale models (like the Fresno model) do not cover multi-class features due to its complexity;
- For peak-hour analysis, we analyze only the AM peak results; PM peak flows are less regular, so PM traffic estimation results are less precise;
- To transform time into monetary cost, we assume an average value of time (VOT) for each user of \$14/hour. Based on the applied average load factor of 1.4 persons/vehicle, the VOT for each vehicle will be \$20/hour (14×1.4);
- Using the EMFAC-2011 model (CARB, 2013), the emission factors (λ_k in Equation 1) are calculated based on the VMT-weighted averages of 2030 emission factors for different vehicle classes at each speed level. Base unit emissions and fuel cost parameters are as follows: \$25/ton

of CO_2, \$250/ ton of CO, \$7,000/ton of NO_x, \$3,000/ton of TOG, \$30,000/ton of PM_{10}, \$300,000/ton of $PM_{2.5}$, and \$4/gallon of gasoline (Wang et al., 1994; McCubbin and Delucchi, 1999; AEA Technology Environment, 2005);

- Travel costs other than time, fuel, and emissions could also impact the results, e.g., accidents. But because of the complex effects of "rat running" (Verhoef, 2007) to other congested roads (higher externalities) and lower travel demand due to higher travel costs with tolls (lower externalities), we decided to neglect these other travel costs;
- A flat, constant, mileage-based toll rate on the whole road (consisting of various segments), is applied by policy makers/road owners. However, the toll rate is different for each time period (temporal variation or peak vs. off-peak prices). The only exceptions are the spatially variable tolling schemes;
- The operating and capital costs of collecting tolls are based on the average estimated cost of two private toll roads, Toronto 407 and Dulles Greenway (Balducci et al., 2011). Specific to the U.S., the operating cost is assumed at \$0.2 per transaction for private systems and at \$0.24 per transaction for more costly publicly-run systems, however, studies have shown that in other sectors, private provision does not systematically result in lower costs (Bel and Warner, 2008; Bel et al., 2010). Nevertheless, scale or learning economies, that cannot be reached by government, could ensure lower unit costs of private provision of a service (De Bettignies and Ross, 2004);
- For the capital cost, considering a 30-year payback period and a 6% discount rate, the annual average capital cost per mile is \$1.2 million for highways and \$1.5 million per mile for arterials because arterials have a greater number of access points;
- Future profits are discounted using a discount rate and demand risk factor combination. The discount rate is assumed to be 6% for the base case. The demand risk factor (risk markup) is used to reflect uncertainties in future toll revenue. It starts at zero and rises to 4 percent in 40 years;
- We assume that toll rates set in P3 contracts remain constant over time. However, in many real-life P3 contracts, the toll rate increases at the Consumer Price Index (CPI), inflation rate, and/or nominal GDP (Bel and Foote, 2009);
- The profits from P3 projects would be distributed among the stakeholders as follows: 10% to government, 30% to the private sector, and 60% to residents. Note that profits (revenues minus costs) are used in our analysis. One can legitimately argue that toll collection costs are also a transfer between two groups (as are revenues), and the costs result in a positive social welfare effect as well (by raising employment). However, we did not take this into account;
- Users are not categorized into inside (with standing) and outside of the region (without standing). In fact, benefits and costs are calculated for all users on average;
- The transaction costs of P3 contracts are assumed to be negligible. Our rationale is that the profits are collected during a relatively long period of time while the P3 contract negotiation is a one-time act;
- Contrary to previous assumptions favoring IP3 schemes, we did not consider delays in delivering (operating) a system which is common for the public provision of transportation services. A major benefit of implementing a P3 approach is the provision of service according to schedule, and a complete social welfare analysis should include these benefits (costs); and

- The welfare weights (δ's in Equation 5) are set equal to one. However, we examine deviations from the base weights in the sensitivity analysis section.

In addition to the above mentioned basic parameters, we run a sensitivity analysis on some of the major parameters in the Results section. The sensitivity analysis clarifies the effects of deviations in the parameters from assumed basic parameters.

3. Results and case study

3.1. *Case study*

The City of Fresno's transportation planning model is the benchmark for our modeling. As shown in Figure 3, we selected seven segments of roads transecting the urban area including four highways: SR168, SR41, SR180, and SR99; and three arterials: Shaw, Shields, and Blackstone, as the candidate for concession projects. The main features of the selected roads can be found in Rouhani et al. (2013*a*).

Fig. 3. Road network of Fresno, California with the candidate roads.
(Source: Transportation planning model, city of Fresno)

3.2. *Results*

We start this section by investigating different sets of decisions (i.e., ownership structures) required for a thorough social welfare analysis of alternative (tolling) schemes. Then, a systematic social welfare analysis is developed to address the effects of IP3s, P3 projects, and other tolling schemes on the major relevant stakeholders' benefits and costs. Finally, we conduct a sensitivity analysis on several key parameters to test our results under different parameters.

3.2.1. *Alternative scenarios*

Table 1 describes the main features of various scenario cases. Cases 1 and 2 represent unlimited profit maximizing scenarios for one of the highways (Highway No.1–SR 168), when toll rates are constant and when they are variable (spatial variation), respectively. Case 3 sums up individual private ownership of each candidate road, i.e., each road is privatized separately (only one private road), but the results are reported together, and the anticipated total profit is the summation of profits from all individual private roads. Case 4 and 5 simulate the ownership of all the candidate roads by one profit maximizing firm (monopoly) and by separate profit maximizing firms (oligopoly).

We also model a system-optimal scenario for which all roads are tolled to minimize system cost (Case 6), which usually implies implementing a publicly-run tolling scheme. Case 7 represents the best two-private-road combination to maximize profits (while also reducing congestion through capping toll rates); Highways No.2 and No.4 are privatized but with limited tolls, which were found using a heuristic approach (Poorzahedy and Rouhani, 2007). Finally, Case 8 represents mixed public and private operation where Highway No.1 is operated by the public sector to minimize system costs without considering its profits, and Highway No.2 and No.4 are operated by the private sector to maximize profits (the best two-private-road combination), but with toll ceilings. In fact, Case 8 is an extension of Case 7 where a public road is added to improve system performance (a mixed-operator solution).

Table 1

Main features of alternative schemes under consideration.

Prior to providing a detailed social welfare analysis, we examine general outcomes under alternative scenarios. Table 2 shows the corresponding hourly revenues, costs, and profits of collecting tolls, for both peak and off-peak periods. Table 2 also reports changes in total system-wide travel costs (other than tolls) of the transportation system as a result of applying the tolling schemes.

Table 2

The overall outcomes of alternative schemes.

Table 2 indicates that for Highway No.1, implementing (spatially) variable tolls in place of flat tolls (Case 2 versus Case1) further increases profits and also improves quality of transportation service. In fact, temporal and spatial flexibilities in toll setting ensure the maximum private sector concession payment. Another implication is that although the system cost minimization (publicly-run or Case 6) tolling scheme would be costly (negative profits), this public scheme could be designed to drastically improve system performance. In fact, the public sector should pay for the toll collection system to ensure system-optimal patterns because its toll collection costs are higher than its revenues.

On the other hand, although the profit maximizing cases (applied on all roads), Cases 4 and 5, result in substantial profit, these cases dramatically increase system total travel costs. As shown in Table 2, the system-optimal case (Case 6) saves $226 million of travel costs while the profit maximizing cases result in a $400 million annual increase in travel costs (monopoly, Case 4), mainly in the peak periods and by diverting traffic from concession roads to highly congested un-tolled roads. However, with more road segments becoming priced (leased), the high toll rates imposed by monopoly and oligopoly cases could also improve service quality, especially when an alternative efficient public transportation system is available (Rouhani and Niemeier, 2011).

From the private sector perspective, competing with priced (especially private) roads is preferable (profitable) to competing with the public (free of charge) roads. Therefore, P3 candidate projects should be analyzed and evaluated together. Implementing P3 projects together provides much higher profits for the private sector and consequently yields greater upfront payments from the private sector. As shown by the difference between Case 3 and Cases 4 and 5, the simple summation of the profits of different P3 projects implemented individually ($116.4 million) is lower than profits made through leasing all seven P3 candidates together ($136 or $120 million). In addition, applying these projects together has important effects on the transportation system's total travel costs. Therefore, a comprehensive analysis of an IP3 approach should definitely examine P3 projects together and even examine the optimal order (time) of implementing these projects.

In fact, the two extreme cases of system optimization and profit maximization usually fall dramatically short of the opposite goals of raising profits and improving system performance, respectively. A successful P3 project raises a significant amount of profits and simultaneously reduces transportation system travel costs. Neither profit maximization nor system cost minimization should be policy-makers' sole targets.

Case 8 represents a scenario where a combination of congestion reduction and profit making goals were used as the criteria for choosing among candidate roads and selecting toll rates. Under this scenario, the private sector operates two profit maximizing toll roads through an IP3 approach (the same private roads under Case 7). In addition, the public sector runs a costly tolling system on another road not only to improve quality of service but also to potentially boost profits on private roads. The latter objective provides greater profits for both government and residents since the profits from P3 projects are partially redistributed to government and residents. As shown in Table 2, Case 8 raises $45 million in toll revenue and decreases travel costs by $170 million annually (Table 2).

3.2.2. *Social welfare analysis*

Using the social welfare analysis framework described in the Methodology section, we estimate the benefits and costs of using an Investment P3 (IP3) approach relative to the do-nothing scenario. Table 3 reports net benefits as well as details about the annual revenue, cost, and profit of various toll collection systems applied for two major stakeholders: government and the private sector. Government's profits are from two major sources: (1) 10% of P3 projects' profits; and (2) profits from implementing publicly-run toll systems. We assume that a privately-run tolling system is more cost effective than a public one and is used in place of a publicly-run tolling system as long as the tolling system is significantly profitable. Therefore, the second source results in negative profits for government (costs > revenues) in all of our studied scenarios. Nevertheless, in practice, a public tolling scheme could also raise positive profits.

Table 3

The government and private sector gains and losses under different ownerships.

Government might not seek the highest social welfare. Politicians may maximize political benefits by lowering current taxes or by providing higher dividends to residents. Based on the economic theory of regulation (Boardman and Vining, 2012), the tendency to seek political benefits may lead policy makers to choose P3 projects that provide higher immediate upfront payments (higher profits only) and do not necessarily improve overall social welfare, specifically system performance. As shown in Table 3, the monopoly and oligopoly cases (Cases 4 and 5, with no toll limit) provide the highest profits from tolling while the same cases drastically lower service quality and total social welfare criteria (as shown in Table 2). In contrast, the system-optimal case costs the public sector $133 million and raises no profits.

Table 4 reports annual benefits and costs of the above-mentioned ownership scenarios for two other major stakeholders (average users and residents). As discussed above, users' social welfare change includes: (1) the average amount paid in tolls over all users; (2) the average change in travel costs other than tolls (time and fuel consumption) over all users; and (3) the average change in social welfare from travel demand decreases over all users. Based on the rule of half (Rouhani and Niemeier, 2011), the last component quantifies the decrease in social welfare when some users decide not to travel due to higher travel costs associated with tolls. Since Fresno's transportation system does not provide a strong public transportation option to users, we do not consider utility reductions as a result of switching from private cars to public systems.

When traffic congestion exists in urban transportation settings, the political benefits of implementing higher tolls (where revenues are partially returned to government or residents) may be aligned with the social welfare goal of a more efficient transportation system (Boardman and Vining, 2012). However, this agreement between political/private and public goals depends importantly on toll setting in P3 contracts. In most of our profit-maximizing scenarios (e.g., monopoly and oligopoly), the application of high unlimited tolls does not improve transportation system performance due to spillover effects onto highly congested roads.

Users enjoy the largest benefits under the system-optimal scenarios, and especially when only one (or few) road(s) is tolled at a system-optimal rate (Cases 2 and 4). As expected, the worst scenarios for users are under the oligopoly and especially monopoly structures since they not only pay high tolls, but system performance becomes worse as well; under the monopoly case, users end up paying $1,500 (in monetary costs) more per annum. Effects are estimated for average users only; motorists who use the roads more than average will lose more. This difference results from a variety of regional (zonal) and income (VOT) factors. However, with redistribution of toll profits through the permanent fund (Kockelman and Kalmanje, 2005) and incorporating transferable utility potentials (Sprumont, 1990), a beneficial scheme for most users is achievable when average users are better-off.

Residents' social welfare change includes two main components: (1) the average health-related changes in emissions costs over all residents; and (2) the dividends to all residents using an IP3 approach. Residents play a key role in selecting P3 projects, so benefits to them are likely to be a major driver for P3 project implementation. As shown in Table 4, emissions costs are negligible relative to dividends.

Dividends are calculated based on a declining principal (instead of perpetuity) approach, for 20 and 50 years of concession periods applying a demand risk factor, as mentioned in the Assumptions section. Our estimated dividends are generally lower than the annual dividends of $1,000 (to each household) found in the Geddes and Nentchev study (2013), for the Columbus, Ohio region. The main reason for the difference is that we assume that only a small set of all urban roads are tolled as P3 concession roads (43 miles in totality).

System-optimal cases work well for average users, although the profits from these cases are negative, and government should pay for the costly toll systems. On the other hand, by using profit maximization cases, government and the private sector can raise substantial profits and be better-off, while travel costs may be dramatically higher and users would be worse-off.

The overall goal should be finding a Pareto-optimal solution where all stakeholders (average users, average residents, and the public and private sectors) are better-off than the do-nothing (i.e., no-tolling) case. Case 8, the mixed ownership scenario, represents a Pareto-optimal improvement. Not only do government and the private sector achieve net benefits of $1.7 million and $14.5 million, the residents and users are also better-off by $6.6 and $90 ($6.5+$82.9 with a 20-year concession) annually. Case 8 is Pareto-optimal despite the fact that under Case 7, in which the same two private roads operate, average users will pay $170 more annually. The key to finding a Pareto-optimal solution is the use of a mixed ownership structure where some road segments are tolled to raise profits, but some other road segments are tolled to improve transportation system performance.

Table 4

Residents' and users' gains and losses under different ownerships.

3.2.3. *Sensitivity analysis*

To provide a reliable social welfare impact analysis of IP3s, we conduct a sensitivity analysis on several key parameters to examine the robustness of our key findings. Under different scenarios, Figure 4 shows the changes in total social welfare when a) travel demand deviates from its base level by 10%; and b) the discount rate differs from its base rate of 6%, and is instead 3% and 9%. Total social welfare in terms of net present value (NPV) is the summation of welfare effects on all stakeholders, in billion dollars and over a 20 year concession period.

The first observation in Figure 4 is that, with base parameters, the mixed ownership scenario (Case 8) provides the highest social welfare, which is positive or increases social welfare relative to the no-tolling case, followed by Case2 (variable toll on Highway No. 1), Case 1 (flat toll on Highway No.1), Case 7 (two best private roads), Case 6 (system-optimal pricing), Case 5 (oligopoly), and Case 4 (monopoly), all of which reduce social welfare relative to do-nothing.

Fig. 4. Sensitivity of total social welfare change with respect to (a) travel demand and (b) discount rate.

As shown in Figure 4–a, for profit maximizing cases (Case 4, 5, and 7), an increase in demand results in an increase in total social welfare (going from low demand to high demand). For the system-optimal case (Case 6), however, an increase in demand mitigates social welfare. This difference in outcomes stems from the fact that, with an increase in demand, profits will grow, and congestion will intensify. As a result, profit maximization cases benefit from an increase in profits while system-optimal cases suffer from amplified congestion costs (travel costs to users). In contrast, a decrease in demand results in the opposite outcome.

Under our assumptions, the change in discount rate multiplies the values of social welfare change by a certain ratio since all stakeholders enjoy similar annual cash flows over time, and the only present expenditure in our analysis (the capital cost of toll collection) is negligible relative to other annual values (Figure 4–b). However, in practice, changes in social welfare as a result of changes in discount rate are more complex since the cash flows differ over the years of analysis, and discount rate is one of the most important factors for evaluating P3 projects.

As we discussed before, the welfare weights (δ's in Equation 5) are crucial for social welfare calculations; policy analysis should determine whose benefits and costs should be included and by what ratios. Figure 5 depicts the outcomes of changing (a) residents' weight and (b) users' weight. The rationale behind increasing residents' weight is that residents could be viewed as the real owners of the transportation infrastructure. Residents' perceptions are the major factor driving the decision regarding IP3 implementation. They can also affect the political will to mobilize the process for the much needed fundamental changes in transportation system provision.

As expected, the increase in residents' weight favors more profitable monopoly and oligopoly cases (Cases 5 and 4). Government (policy makers) selects the approaches that patronize its goal of maximizing votes. Implementing the profit maximizing scenarios, government may gain political benefits by increasing residents' support by providing high dividends, balancing the budget, boosting the private sector's profits, and keeping current fuel (or other) taxes low. However, the overall outcome of the highest social welfare for the mixed ownership scenario (Case 5) does not change unless very high residents' weights (e.g., 20 in Figure 5–a where all other weights are one) are applied.

Fig. 5. Sensitivity of total social welfare change with respect to (a) residents' welfare and (b) users' welfare.

In addition to increasing residents' weight, policy makers could use a lower users' weight than unity since some users could be foreigners without equal standing in the social welfare calculations. As shown in Figure 5–b, profit maximizing cases benefit more from a decrease in users' weight. However, using a relatively reasonable weight like 0.5 or higher (50% of users of an urban system might be foreigners; at most), the mixed ownership scenario still provides the highest social welfare. Note that the Interstate Commerce Clause of the Constitution (Article I, Section 8, Clause 3) prevents the U.S. states from interfering with commerce using pricing strategies, tolling interstates to "beggar thy neighbor" would be an example (Commerce Clause, 2013). Therefore, social welfare calculations are more complex than excluding or including users from outside the region, legally.

Although highly effective on the results, an average VOT (not a detailed stratified VOT distribution) only affects the trade-offs between money (tolls) and time. Under the same traffic flow pattern (the same time cost), a higher average VOT will result in a higher optimal toll rate (monetary) and consequently a higher revenue by a constant ratio. However, changes in profits are not as smooth as changes in revenue since toll collection costs remains constant when changing VOT. Figure 6 shows how social welfare is affected by deviations in VOT. In most cases, an increase in VOT appears to magnify the total social welfare both positively and negatively. The reason is that increasing (decreasing) VOT first, will increase (decrease) profits since users are more (less) willing to pay for a better service, and second, will increase (decrease) travel costs since time costs is linearly dependent on VOT. Nevertheless, Case 6 –the system optimal case– is an exception of this rule; total social welfare is negative but becomes positive with a $40 VOT. For a congestion management case, increasing VOT will boost travel cost savings in monetary terms while it also raises revenue.

Fig. 6. Sensitivity of total social welfare change with respect to value of time (VOT)

We also analyze variations in operating costs of public toll collection systems. For our base case, as discussed in the assumptions section, the operating cost of public systems is assumed to be 20% higher than that of private systems based on the Balducci et al. study (2011) on North American tolled roads. Here, we relax this assumption and consider various ratios of public to private system's operating costs (per transaction). This assumption only affects Cases 6 and 8 since these are the only cases with public toll roads.

Figure 7 show how total social welfare and profits will change when changing the operating cost ratios. As can be seen in Figure 7, total social welfare changes depend on changes in profits since operating costs only affects profits; a change in operating cost has no impact on system-optimal toll rates. Another observation is that variations in the ratio have relatively small effects on the final outcome, however, the effects are greater for all-public system (Case 6, Figure 7–a). Nevertheless, Case 8 again provides the highest change in social welfare, with all the ratios applied. As shown in De Bettignies and Ross (2004), lower operating costs for private systems may entail a lower quality of service or lower wages paid. Here, we did not consider such relationship between toll collection costs and quality of service.

Fig. 7. Sensitivity of total social welfare change to public-private operating cost ratios for (a) Case 6; and (b) Case 8.

4. Conclusions

In this study, we develop a general social welfare analysis framework including the major stakeholders of IP3 schemes (residents, users, government, and the private sector) and estimate the social welfare change from implementing IP3 alternatives for an urban city. Our modeling suffers from several simplifications. First, potential improvements in transportation and urban systems are neglected. P3 profits (upfront payments) can be used to improve transportation system but since the IP3 approach assumes that the main portion of P3 profits will be redistributed to residents, we did not account for these potential improvements.

Second, our analysis is based on average effects while a more detailed analysis should take the effects on different groups of user/residents into account, especially from an equity perspective. Third, our model simulates a static process, so it fails to capture potential dynamics between different time periods in the long-run and the possible difference in annual toll profits and system travel costs in different years. Finally, the employed benchmark modeling could be improved by using multi-user equilibrium (Yang and Huang, 2004) and considering heterogeneity in VOT of users (Small, 2012), more detailed analysis of travel demand uncertainty (Chen and Subprasom, 2007), quantification and optimal allocation of risk (Jin and Zhang, 2011), and more advanced objective functions than abstract profit maximization and system cost minimization. Nevertheless, our modeling framework and our results provide the foundation for future social welfare studies evaluating transportation P3 projects.

Our results show that system-optimal schemes (tolls) could decrease total travel costs incurred by average users, but government should pay for the costly toll systems. In contrast, unlimited profit maximization schemes (tolls) raise substantial profits for government, residents, and the private sector while users incur huge increases in their transportation costs through both toll payments and higher travel time and fuel consumption costs. From the public interest aspect, policy makers should search for a Pareto-optimal solution where all stakeholders are better-off, on average. One of our scenarios, which simulates a mixed private and public tolling scheme with mixed profit maximization and system cost minimization goals, represents a Pareto-optimal improvement. Government, residents, users, and the private sector are all better-off than the no-tolling case. Using our base assumptions, the mixed scheme in the case study increases total social welfare by close to $500 million over a 20 year period.

Our sensitivity analysis show that changes in major factors such as travel demand level, discount rate, welfare weights, and value of time (VOT) do not affect the ultimate outcome that the mixed tolling scheme provides the highest social welfare, unless such changes are remarkable. However, a decrease in users' weight and an increase in residents' weight seem reasonable since some users are not from the region (they do not have equal standing in social welfare calculations unless legal constraints do not allow this), and residents play important roles in the success of an IP3 approach.

Future work could develop a more in-depth social welfare analysis which will account for the equity effects on different groups of users and residents. In addition, certain types of risks associated with the P3 project delivery should be quantified and considered in the social welfare analysis in greater detail. Finally, the effects on factors outside the transportation sector such as employment, land-use, and work-hours should also be taken into account.

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