Understanding the Interaction of Multiple Jurisdictions for Highway Investment: Viability of Public-Private Partnership Alternatives

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ABSTRACT

Observing that highway public-private partnerships (P3s) have been rare for projects that cross jurisdictional boundaries, this study attempts to evaluate strategic interactions of multiple governments in terms of their road network investment, with the prospect to partner with a private firm. There is a gap in the literature regarding network level analyses of investment behavior in partnership with the private sector. In undertaking this complex analysis, this paper presents a model with which to investigate how governments strategically interact with each other in making these decisions. Numerical analysis of the model on a highly stylized highway network was conducted to serve as the foundation for investigating various complex policy alternatives not only on stylized networks but also on real highway networks. The analysis demonstrated that two jurisdictions, in maximizing respective welfare given the best response of the counterpart, raised toll and increased the capacity for the link that served inter-jurisdictional commuters, relative to the other links. Welfare losses and negative profitability resulted. The analysis suggested the analytical framework could be a tool to inform decision makers on possible consequences of various policy scenarios, including the use of P3s for such contexts.

Keywords: Public-Private Partnerships, Government Competition, Highway Investment, Road Pricing

INTRODUCTION

Urban regions in the U.S. continue to experience growing surface travel demand, and a number of states struggle to keep up with the need for capacity expansion while maintaining rapidly aging assets. The traditional Highway Trust Fund supported with gasoline tax revenues has diminished purchasing power due to improved motor vehicle fuel efficiency and the public's aversion to raising the gasoline tax. In response, states and municipalities today employ a number of innovative policy tools, including notably public-private partnerships (P3s).

There is no jurisdictional boundary to economic activities in a region, which means the demand for intra-regional travel that also crosses state lines can complicate the transportation planning process for metropolitan regions. The federal system in the U.S. is unique to give each state substantial autonomy, making cross-state coordination of network infrastructure investment and adding an important dimension to policy-making processes. States use multiple approaches to manage the investment in and maintenance of surface transportation facilities that cross state borders. In some cases, state borders act as the definitive boundary to the activities of asset owners. In other cases, especially for large facilities with regional or national significance, states on both sides of the border collaborate to create an agency that is responsible for designing, constructing, operating and maintaining the facilities.

The interstate compact is a sustainable mechanism by which states collaborate with one another to address a variety of policy issues that extend beyond their borders but not so far as nation-wide *(1)*. Interstate compacts are used to define an institutional framework for cooperative policy action among multiple states *(2)*. If the use of an interstate compact is too costly, as it requires congressional approval, a looser mechanism, such as signing a memorandum of understanding (MOU), may be an alternative that governments may use.

These mechanisms of inter-jurisdictional collaboration are complex in their own right. Consideration of a P3 procurement alternative adds yet another layer of complexity to the institutional arrangement of multi-jurisdictional collaboration mechanisms. Despite the increasing number of surface transportation P3s across the nation, only in limited cases have P3 mechanisms been employed in cross-state contexts.

The Ohio River Bridges Project in the Louisville, KY metropolitan region is one of the few cross-border facility P3 projects. The project consists of a \$1.27 billion Downtown Crossing project, which includes a new bridge on I-65 and rehabilitation of the existing Kenny Bridge near Downtown Louisville, and a \$1.45 billion East End Bridge project, which includes the construction of a 7.5mile extension of I-265 with a bridge and a tunnel *(3)*. The Commonwealth of Kentucky is responsible for the Downtown Crossing project, using a traditional procurement approach including municipal bonds and other debt financing arrangements. The State of Indiana has formed an availability payment P3 for delivering the East End Bridge project with mostly private financing. Both projects will be tolled, and the revenue will be equally split between Indiana and Kentucky. With the revenue, the Kentucky Public Transportation Infrastructure Authority and the Kentucky Transportation Cabinet will be responsible for debt repayment and the operation and maintenance of the Downtown Bridge Project. The Indiana Department of Transportation is responsible for the availability payment to the private partner for the East End Project, whether the toll revenue is be sufficient or not *(4)(5)*.

Initially proposed nearly 50 years ago, the project began moving forward in 2010, when the Louisville and Southern Indiana Bridges Authority (LSIBA), a bi-state compact agency between Kentucky and Indiana, was formed, pursuant to Kentucky Revised Statutes Section 175B-030. Indiana Governor Mitch Daniels issued an executive order in December 2009 to authorize the State of Indiana to participate in the interstate compact, and the Kentucky General Assembly ratified the creation of the agency in March 2010 *(6)*.

The LSIBA explored alternative financing strategies for the project, and recommended that the Downtown Bridge Project be constructed through a design-build approach with traditional tax-exempt bonds, and the East End Bridge be privately financed through a P3 with an availability payment arrangement. In March 2012, the governors of both states signed a memorandum of understanding outlining each state's role in the project. In this agreement, the Commonwealth of Kentucky was responsible for the Downtown Bridge Project through a design-build contract with traditional funding, and the State of Indiana employed a P3 approach to build the East End Bridge Project. The bi-state Bridge Authority approved the financial plan for the project, and the Kentucky Transportation Cabinet, Indiana Financial Authority, and the INDOT then finalized a bi-state development agreement to govern the financing, construction, and management of the project *(6)*.

It is important to recognize the role that the bi-state compact agency plays in this project, along with other entities involved in the project management and oversight. The terms of the compact requires that projects that connect Indiana and Kentucky be constructed and financed by a bi-state authority. Further, the Louisville Southern Indiana Bridge Authority is charged with developing a financial plan of the project, as well as other requirements in the terms of the compact (e.g. annual report to both states, as required in the development agreement). A bi-state management team, with representatives from KYTC, INDOT, and FHWA, is responsible for the overall project management. A joint board is responsible for conflict resolution for the bi-state management team. KYTC and KPTIA are the project sponsors on the Kentucky side, and INDOT and IFA are the project sponsor on the Indiana side. A toll system integrator was formed as set forth in the bi-state Development Agreement *(6)*.

Importantly, the example of the Ohio River Bridges Project points to the flexibility of P3 alternatives for cross-border network facilities. The use of P3s is not necessarily constrained to a single model, for instance, where a bi-state agency is authorized to form a P3 with a private firm. Therefore, it is important to understand not only the particular institutional framework, which is unique across U.S. states, but also the factors that drive such cooperation behind the institutions. As such, we believe it is worth inquiring whether inter-jurisdictional P3s are worthwhile for a specific project, and why two jurisdictions might collaborate with one another. Answering these questions requires understanding the factors that drive interactions between multiple jurisdictions compared to their business-as-usual models, as well as how the relationship might change when private firms are potentially involved in delivering the infrastructure service.

The objective of this study is to develop an analytical framework to help policy makers gain insight into the factors involved in such undertakings and their potential consequences. Following the literature on intergovernmental competitions for network infrastructure, considering capacity and tolling behaviors, we examine the consequences of alternative policy scenarios with respect to travel demand, highway capacities provided, profit levels of private firms, and the social welfare. The analysis will use a highly stylized network model with a number of strict assumptions. Therefore, the intent of this study is to serve as the foundation for future studies that might extend the model to a more realistic network. Yet, the findings will still be insightful for policy makers.

The remainder of the paper is structured as follows. The next section will review relevant literature. The section that follows will present the analytical framework used in this study. After summarizing the numerical results, the last section will discuss policy lessons as well as directions for future analysis.

LITERATURE REVIEW

Scholars have extensively discussed the subject of governments' highway investment, often in the context of the principles of road pricing. A particular focus on the interaction of governments while making these decisions emerged rather recently in the 2000s. One of the notable features in the recent literature is its emphasis on the network level analysis of horizontally competing operators (e.g., competition among states). This literature review will focus on some of these recent studies that are relevant to the analysis in this study.

Strategic pricing and investment behaviors of road operators was first formally analyzed by De Palma and Lindsey, who investigated the welfare effect of ownership types on parallel links of an origin-destination (OD) pair, using a dynamic congestion bottleneck model *(7)(8)*. De Borger et al. conducted an equivalent analysis in the context of two public operators with tolls: parallel links that connect a city and a suburb were proposed for the analysis. Local traffic and cross-border traffic were differentiated, and potential tax competition between the public operators was analyzed. While this study led to important policy insights regarding tolling behaviors of governments (distinguishing local and through traffic), this study did not address highway capacity investments *(9)*.

More importantly, a number of studies have investigated, in the context of serial road networks, the strategic interaction of public road operators regarding their pricing and investment decisions. A typical case of such a network is two links that are connected at the border of two abstract regions, such as two uniform jurisdictions, or more interestingly, a city and suburb. Among those, several studies focused their analyses on pricing and investment behaviors, as opposed to pricing only. De Borger et al. proposed a game theoretic model of a serial network where two public authorities strategically decide road capacity and toll level in a two-stage game. They found a double-marginalization of cross-border traffic, where public authorities set tolls higher than marginal cost pricing levels to extract revenues, disregarding the losses incurred to the other public authority. This study found that, when one jurisdiction increases the capacity, general travel cost decreases, followed by an increase in the traffic level. The other jurisdiction then responds by increasing its capacity as well *(10)*. Notably, this analysis was conducted in the international context: jurisdictions were nations. However, the modeling framework and insights are relevant to the state and municipal levels, although intergovernmental transfers (if relevant at all) would not be included.

Ubbels and Verhoef analyzed strategic interactions of governments using a similar approach, employing Nash and Stackelberg games, which illustrate the effect of timing of decisions. The results of their analysis suggest that it doesn't make much difference whether decisions are made simultaneously or sequentially, especially with regard to the welfare effect of alternative policies *(11)*. Other studies on two governments' interactions on strategic road capacity choice on serial network include two reports by Mun and Nakagawa, De Borger et al., and De Borger and Pauwels *(11)(12)(13)(14)*.

With the emergence of P3s as commonly employed procurement mechanisms in the U.S., scholars have investigated various aspects of the policy instrument. Besides the literature on incomplete contract theory framework on P3s (e.g., Value for Money *ex ante* project evaluation models) financial models (e.g., option theory-based financial model to account for risks), and many others, a growing number of studies attempt to model outcomes of strategic behaviors of project partners. Game theories have been commonly used on the subject of infrastructure P3s, and there appears to be considerable room for further development, where game theoretic models can serve as a powerful analytical tool for drawing valuable policy insights.

One of the possible avenues through which the game theory approach can be used is to focus on initial project negotiations between the public and private partners. Due to its complex nature, negotiations for P3 projects to reach commercial and financial close are lengthy and involve considering a number of project dimensions. In particular, since allocation of project risks to the party best able to manage them is considered a requirement for a successful P3, public and private partners spend a considerable amount of effort aligning risks in a mutually beneficial manner. Medda proposed a final arbitration game so as to evaluate how opposite interests of public and private partners would play out in the negotiation. The result indicated that strategic behaviors of partners prevail when the value of public guarantees exceed financial loss, potentially triggering moral hazard situations *(15)*.

Ho focused on renegotiations of P3s, which take place when project performance does not meet expectations as of financial close (e.g., lower than expected revenue stream, unexpectedly high operational expenses). Both static and dynamic games were proposed to evaluate the factors that contribute to the public partners' decision to rescue a distressed project through financial renegotiations with the private partner. The author argued that renegotiations could never be ruled out in a project; the probability of reaching a "rescue equilibrium" should be minimized; the interval of the renegotiation offer zone should be minimized; during negotiations, the public authority should spend more resources on trying to reach the lower bound of the renegotiation offer zone; and that the government should not focus on developing negotiation skills, but rather focus on objectively evaluating the impact on the project and communicating the outcomes with private firms *(16)*.

One of the contractual complexities of P3s that partners must evaluate and agree upon is the length of concession terms. There are several models that have been used in practice, yet literature continues to evolve in proposing refined evaluation models. Peng et al. proposed a Stackelberg game model based on the options theory framework to include an option to expand the project before the concession term's completion. Through a numerical analysis using parameters from the First Coast Outer Beltway project in Florida, the authors demonstrated prospects for practical implementation in the future *(17)*.

The use of game theory models appears to be rapidly growing in the last several years. A research team at Cornell University has been proposing investment public private partnerships (IP3), which is a toll revenue based fund that partners with private firms to operate and maintain existing highway facilities (i.e., brownfield) and commit a significant share of toll revenues to reinvest in local communities. In evaluating the welfare effect of a proposed IP3, Huang and Gao conducted a multi-leader-multi-follower Stackelberg Game *(18)*, while Rouhani and his collaborators conducted similar welfare analysis of the proposed policy instruments *(19)(20)*.

The review in this section focused on theoretical analysis of strategic interactions of governments in terms of road capacity decisions in a serial network context, as well as the use of game theory analysis in a P3 related context. Regarding the literature on government competitions with respect to capacity and toll setting, the analyses are very simple using linear demand and travel cost functions and refraining from analytically intractable problems. Although the insights from these studies are important, there are several ways in which the analyses could be extended. First, previous studies indicate that the network structures demonstrated larger impacts than other factors, such as types of games assumed *(8)*. In particular, we have not found a study that analyzed jurisdictional interactions where a network link exclusively served commuting traffic. In our view, such an extension would be an important step toward understanding the relationships between institutional frameworks and behaviors of decision makers regarding highway capacity investments. Furthermore, one may expect different outcomes of strategic interactions among players, when accounting for different ownership types or more complex ownership arrangements, as they would imply distinct objective functions of players in the game. Another important extension to this line of literature will be to generalize the analysis setting to a more complex network that looks like a real road network over multiple jurisdictions.

MODEL

In order to model the interaction of multiple jurisdictions for highway network investment, we focused on the travel demand on a given network, the user cost of making a trip, the cost of investing in the network capacity, and tolls charged for each link. We closely followed the model proposed by Ubbels and Verhoef (2008). We used a highly stylized network for the analysis, presented in Figure 1. The model consists of two jurisdictions m = {c, s}, c representing a central city and s representing a suburban city. “City” in this analysis merely represents a jurisdiction that is the public owner of an infrastructure asset. In a P3, therefore, the city can serve as the public agency to partner with a private firm. The network consists of three links, denoted i = {1, 2, 3}, where link 1 is entirely in the central city, link 2 is solely for the cross border traffic, and link 3 is entirely in the suburban city. The road serves three types of groups, denoted j = {c, t, s}, where group c is the central city’s local travel demand, group t commutes from the suburban city to the central city, and group s is the local travel demand of the suburb. For simplicity, we only considered one direction of travel (from suburban city to central city) and not the reverse commute.

Our analysis is distinct from Ubblels and Verhoef (2008) in several important ways. First, the network structure accounts for a link that serves exclusively commuting travel from one jurisdiction to the other. Also, we assume a static model where both network capacity and toll levels are simultaneously evaluated.

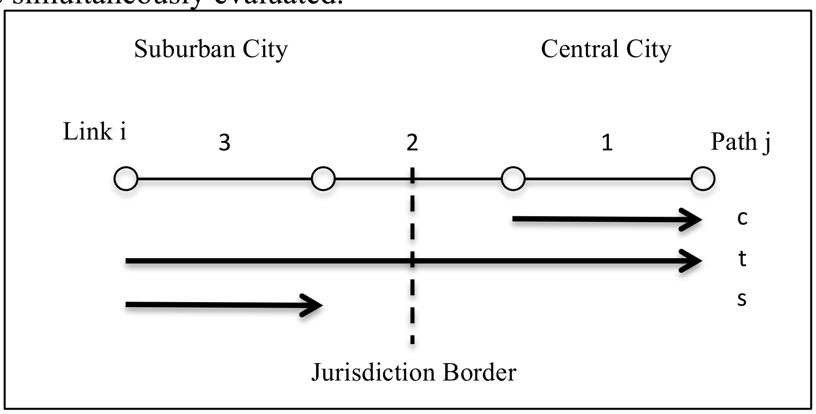

Figure 1 Model Structure

Key variables used in the analysis include road capacity F_i and toll charges τ_i. The road capacity affects the users’ travel costs and the costs of investing in the capacity. The toll also affects the users’ aggregate costs of travel and the revenue for the road operator. Under the traditional model of public procurement and operation of highway networks, governments are modeled to maximize total surplus (Marshallian benefit); that is the sum of utility for residents to make the trip minus the users’ total cost of making the travel, including the cost of time, minus the costs of road capacity, and the transfer of toll revenue between the governments where appropriate.

For tractability of the model, we assume a simple linear demand function and a cost function. The inverse demand function is modeled as follows:

$$D_j = d_j - a_j N_j \tag{1}$$

where D_j is the generalized travel cost on path j as a function of the travel demand. d_j and a_j are parameters exogenously given to the model. N_j represents the traffic volume of path j. Generalized user cost function of travel is assumed to include time, fuel, and other costs except tolls for making a trip. We assume the function to be homogenous of degree zero in use and capacity, and when the capacity is given, it is assumed to be linear. The function is modeled as follows:

$$t_i = k_i + b_i\left(\frac{N_i}{F_i}\right) \tag{2}$$

where t_i is the generalized user cost of travel, F_i is the capacity of the road, and k_i and b_i are exogenously given parameters. Traffic flow for each link $N_i \in \{N_1, N_2, N_3\}$ is the sum of N_j for each link such that: $N_1 = N_c + N_t$; $N_2 = N_t$.; $N_3 = N_t + N_s$.

The cost of capacity investment assumes a simple linear model:

$$C_i = PC \cdot F_i \tag{3}$$

where PC is the unit cost of investing in the road capacity. We assume a constant economy of scale for simplicity in this analysis. Also, the analysis assumes no intergovernmental transfer such as the Highway Trust Fund for the highway capacity investment. Hence the system assumes self-financing.

The aggregate travel cost of users for traveling through each link is the sum of the average user cost and tolls to be charged for the link:

$$p_i = t_i + \tau_i \tag{4}$$

User equilibrium of the network for each link is estimated by equating the aggregate travel cost and the demand for each path, solving for the traffic flow on each link.

The central city seeks to maximize the welfare of its citizens, represented as follows:

$$W_c = \int_0^{N_c} D_c(n)dn - N_c \cdot t_1 - PC \cdot (F_1 + r_c \cdot F_2) + \tau_1 \cdot N_t + r_c \cdot \tau_2 \cdot N_t \tag{5}$$

The first two terms represent the user surplus of travel demand within the central city. The third term represents the cost for providing transportation infrastructure, where r_c is the share of the central city for capacity investment costs. We also assume the same proportion will be used to split toll revenues from link 2 that crosses the jurisdictional boundary. For example, if the capacity cost share is 50%, then the revenue share is also 50%. Therefore, the fourth term and the fifth term represent the toll revenue from non-resident users of the central city (those from the suburban city). Note that the toll revenue from local residents is cancelled off because it is the costs to its citizens but it is the revenue for the same jurisdiction.

The suburban city seeks to maximize the welfare of its citizens, and is modeled as follows:

$$W_c = \int_0^{N_t} D_t(n)dn + \int_0^{N_s} D_s(n)dn - N_t \cdot (t_1 + t_2 + t_3) - N_s \cdot t_3 - PC \cdot (F_3 + r_s \cdot F_2) - N_t \cdot (\tau_1 + r_c \cdot \tau_2) \tag{6}$$

where $r_s = 1 - r_c$. The difference of welfare function for the suburban city compared to that for the central city is that the former considers two user groups: those who travel with the suburban city and those who cross the jurisdiction boundary.

Global welfare is a function that sums the central and suburban cities' models, where tolls are cancelled off:

$$W_g = \int_0^{N_c} D_c(n)dn + \int_0^{N_t} D_t(n)dn + \int_0^{N_s} D_s(n)dn - N_c \cdot t_1 - N_t \cdot (t_1 + t_2 + t_3) - N_s \cdot t_3 - PC \cdot (F_1 + F_2 + F_3) \tag{7}$$

Governments seek to maximize these functions, subject to the following constraints, which represent network travel user equilibrium:

$$D_c = p_c \tag{8}$$

$$D_t = p_t \tag{9}$$

$$D_s = p_s \tag{10}$$

Maximization of the global welfare function is equivalent to the first-best scenario where the toll charged for each link equates the marginal cost pricing, which can be analytically solved by taking the first order derivative of the function and solving it for the toll variables. The tolls is: $\tau_1 = N_1 \frac{\partial t_1}{\partial N_c}$, $\tau_2 = N_1(\frac{\partial t_1}{\partial N_t} - \frac{\partial t_1}{\partial N_c}) + N_2 \frac{\partial t_2}{\partial N_t} + N_3(\frac{\partial t_3}{\partial N_t} - \frac{\partial t_3}{\partial N_s})$, $\tau_3 = N_3 \frac{\partial t_3}{\partial N_s}$. Also, the optimal level of capacity investment for each link can be obtained similarly: $PC = -\frac{\partial t_1}{\partial F_1}(N_c + N_t)$, $PC = -N_t \frac{\partial t_2}{\partial F_2}$, and $PC = -\frac{\partial t_3}{\partial F_3}(N_t + N_s)$.

While the above models represent ideal objective from the government's perspective, it should be pointed out that particularly in the U.S., P3 projects appear to be subject to rules set forth by the government or the legislature. The private partner can freely decide neither the capacity nor the toll levels. For example, it is possible for the government to allow P3 capacity expansion projects only for projects listed in the Long Range Transportation Plan, while toll levels can only be decided in the legislature. In such cases, the decision making process of the P3 entities may look closer to a government agency than a profit driven company.

We are also interested in the behavior of completely for-profit private firms to partner with the government to deliver the infrastructure service to citizens. In such case, the P3 entity will determine the capacity to be provided and the toll levels, with the objective of profit maximization. Assuming a P3 for the entire system, the profit function will be as follows:

$$P_g = \tau_1 \cdot (N_c + N_t + N_s) - PC \cdot (F_1 + F_2 + F_3) \quad (11)$$

Road capacity and the toll level can be derived by evaluating the first order condition of equation 1 in conjunction with equations 1 to 4.

Similarly, the profit function of the central city and the suburban city, respectively, are as follows:

$$P_c = \tau_1 \cdot (N_c + N_t) + \tau_2 \cdot r_c \cdot N_t - PC \cdot (F_1 + r_c \cdot F_2) \quad (12)$$

$$P_s = r_c \cdot \tau_2 \cdot N_t + \tau_3 \cdot (N_t + N_s) - PC \cdot (F_1 + r_c \cdot F_2) \quad (13)$$

In this analysis, we numerically solve for the problems under various policy scenarios and compare the results, in terms of traffic flow, toll level, and capacity for each link and path, as well as welfare and profit for each jurisdiction.

TABLE 1 Summary of Notation

Variable	Explanation
a_i, d_j	Parameter of travel demand
b_j	Parameter of the effect of congestion upon generalized travel cost
C_i	Total cost of capacity investment of link i
D_j	Inverse travel demand of path j
F_i	Road capacity of link i
k_i	Non-negative parameter that represents free-flow generalized cost
N_i	Traffic flow of link i
N_j	Traffic flow of path j
p_i	Aggregate travel cost of travel on link i i.e., sum of generalized user cost and toll
P_m	Profit of jurisdiction m
PC	Unit cost of road capacity
r_m	Share of investment cost and toll revenue for jurisdiction m
t_i	Generalized user cost of travel on link i
τ_i	Toll charged on link i
W_m	Aggregate welfare of jurisdiction m

NUMERICAL RESULTS

Base Case

In this study, we are going to evaluate system performance under different scenarios, all of which will be compared to a benchmark scenario. In the base case scenario, all parameters will be given exogenously. We assumed: a = 0.6; d_c = 350; d_t = 200; d_s = 350; k = 5; b = 0.15; PC = 1.2; and, we also assume an equal split of investment and revenue between the two jurisdictions, r_c = 0.5. Implication of non-equal partnership for system performance will be evaluated in future study. Note that these are arbitrary parameters, and the results can only be used in relative contexts among alternative policy scenarios. The results of the base case scenario as well as all the other scenarios, with respect to the endogenous variables, are summarized on Table 2. Table 3 presents the results of these scenarios regarding the welfare and profit in each scenario.

First Best Scenario – Global Welfare Maximization

While analytical results of the model for some of the scenarios in this section's analysis can be obtained, the intent of this study is to propose a framework by which more complex scenarios can be evaluated. Therefore, we adopted numerical analysis approach to evaluate the decisions and system performance in all scenarios, which can be systematically generalized to investigate more complicated problems in future studies.

The first best scenario was estimated by maximizing the global welfare function. The following initial parameters were used for numerical estimation of the maximum of the function: $\tau_1 = 5$; $\tau_2 = 10$; $\tau_3 = 5$; $F_1 = 100$; $F_2 = 50$; $F_3 = 100$; $N_c = 333$; $N_t = 222$; and $N_s = 333$. The same initial parameters were used for all the other scenarios and the results will be compared against all the other scenarios. We used the sequential least squares programming algorithm to solve the problem *(21)*, for this and all other maximizations.

Second Best – Central City and Suburban City Welfare Maximization

In the second best scenarios, we first experimented the scenario where the central city maximizes its welfare function. Maximizing W_c while holding τ_3 and F_3 constant, τ_1 became substantively higher than in the first best scenario. The central city is assuming considerable mark-up from the conventional Pigouvian tax level toll charge. While the higher toll hurts the local residents, residents of the suburban city who commute to the central city have a larger share of the travel on link 1. The benefit will be internalized by the central city, and the welfare of the central city is higher than the first best scenario, while the global welfare decreased from the global welfare maximization scenario.

We then experimented the scenario where the suburban city's welfare function was maximized, holding τ_1 and F_1 constant. In essence, symmetric results from the aforementioned central city F_1's welfare maximization were obtained: τ_3 and F_3 drastically increased, while the share of local traffic decreased in the suburban city link. Compared with the first best scenario, where τ_2 was much higher than the other links, τ_2 for both second best scenarios (welfare maximization of either the central or the suburban city welfare function) was considerably low. F_2 appeared to be more comparable across these scenarios and did not change as much as τ_2 did.

Nash Game of Central and Suburban City, Capacity and Toll

In investigating the strategic interaction of the two jurisdictions, we assumed a Nash game where both jurisdictions optimize the respective behavioral model, accounting for the best response function of the other player. Several assumptions were made in using the framework. First, it assumed that all players are rational and strictly abide by the respective behavioral model. Second, all players know the payoff functions and they are aware that this knowledge is known by everyone.

Two types of Nash game scenarios were analyzed First, using both capacity and tolls as decision variables. Each of the two jurisdictions determines the level of the two variables, accounting for the best response function of the other jurisdiction. The best response functions were obtained by taking the first derivatives of the welfare functions of both jurisdictions and solving for τ_2 and F_2. The best functions with respect to τ_2 were then equated to be part of the set of best functions to be solved system-wide, while the best response functions with respect to F_2 were equivalent for both jurisdictions, hence included in the system as it was. The best response function of the central city with respect to τ_1 and F_1, as well as the best response function of the suburban city with respect to τ_3 and F_3 were included in the set of equations to solve.

Furthermore, three equations with regard to the user equilibrium, where the utility of each travel path was equated to the aggregate costs of travel, consisting of the average user costs and toll for each link. Overall, the game consists of nine equations with nine unknown variables, allowing for a numerical solution.

The result of the game demonstrated that both jurisdictions try to extract the commuters from the suburban city to the central city by setting the τ_2 very high while τ_1 and τ_3 were kept low. The magnitude of F_2 investment was unreasonably higher than in the other scenarios. As a result of the excessively high toll for the link that connects the two jurisdictions, the traffic volume on the commuter path from the suburb to the central city was virtually non-existent. Both welfare and profit of the central and suburban cities were negative. Hence global welfare and profit were negative with considerable magnitude, unlike any other scenarios.

TABLE 2 Numerical Results, Parameters

	τ_1	τ_2	τ_3	F_1	F_2	F_3	N_C	N_T	N_S
Base Case	5	10	5	100	50	100	333	222	333
First Best (Global Welfare Max)	0.424	170.323	62.842	438.421	147.387	319.425	823.587	416.715	719.374
Second Best (Central Welfare Max)	158.926	1.20804	5	384.646	186.752	100	559.416	528.341	813.313
Second Best (Suburb Welfare Max)	5	-1.39E-09	159.085	100	229.493	276.028	813.309	529.937	558.872
Welfare Nash Capacity&Toll	0.599	480.840	1.198	205.758	1.53E+08	102.860	823.001	0.938	821.006
Welfare Nash Toll Only	1.239	476.954	1.239	100	50	100	820.870	5.125	820.870
Profit Global Max	468.966	3.586	3163678	0.502	43.390	10.293	814.604	1946876	991045.4

Sources: Authors' calculation

TABLE 3 Numerical Results, Welfare and Profit

	Glob_Welfare	Centr_Welfare	Subrb_Welfare	Profit_Global	Profit_Central	Profit_Suburb
Base Case	336440.70	133388.55	204162.15	7470	3735	3735
First Best (Global Welfare Max)	481851.78	238887.48	243140.83	141809.4	35938.94	106410.4
Second Best (Central Welfare Max)	450220.00	266502.51	267684.74	179413.9	172618.5	6795.347
Second Best (Suburb Welfare Max)	469358.92	204899.77	267108.83	179209.8	6458.531	172744.3
Welfare Nash Capacity&Toll	-1.83E+08	-9.14E+07	-9.14E+07	-1.83E+08	-9.16E+07	-9.16E+07
Welfare Nash Toll Only	407866.99	203629.47	204243.87	247441.6	123720.8	123720.8
Profit Global Max	-3.48E+12	4.42E+08	-3.48E+12	9.30E+12	9.17E+08	9.29E+12

Sources: Authors' calculation

Nash Game of Central and Suburban City, Capacity Held Constant

Second, we also modeled a Nash game where the capacity variables are held constant at the initial level. The outcomes were somewhat similar to the Nash game where both toll and capacity assumed the best response functions of the other government: both jurisdictions extracted from the commuter traffic on link 2 by setting the toll high, and, as a result, the level of traffic on the link was extremely small compared to the other travel paths. Welfare of the central and suburban cities was positive, but lower than all the other welfare maximization scenarios, while profits of both jurisdictions were higher than the other welfare maximization scenarios.

Global Profit Maximization – P3 between Inter-city Agency and a Private Partner

Finally, the global profit function was maximized to evaluate full privatization of the system. Evidently, the tolls for local links (τ_1 and τ_3) were set considerably higher than in the other scenarios, while the capacity levels for the same links were kept very small, to minimize the costs of providing the service. With regard to welfare, the global profit maximization scenario resulted in larger welfare gains for the central city than any other scenarios, but with negative welfare for the suburban city, larger than in any other scenarios. Because the magnitude of the suburban welfare loss was larger than the surplus of the central city, the global welfare was negative. The outcomes in terms of profit were positive for both the central city and the suburban city, but the magnitude of the central city's profit overwhelmed that of the central city.

DISCUSSION AND CONCLUDING REMARKS

This study outlined an analytical framework to investigate the dynamics of multiple jurisdictions investing in road networks, so as to gain insights about why there are very few P3 projects in cross-jurisdictional contexts. The literature identified how scholars have investigated the strategic interaction of governments in cross-border road facilities. The review demonstrated that the potential to develop a partnership with private firms to deliver these facilities remains as the literature gap.

This study uses a travel demand, generalized user cost model of travel, and a simple capital investment function, as part of a game theory problem of central and suburban cities. Because of the complexity involved in the proposed analysis, a stylized model was used as a starting point.

The analysis suggests that when both jurisdictions account for the best response function of the counterparty with respect to the capacity and toll of the link that is collaboratively developed and operated, equilibrium can be found with welfare in the negative region. Extraction from the link that connects the two regions was observed, and the toll was set extremely high, while the traffic volume of the commuters from the suburban city to the central city became virtually non-existent.

We conducted two types of Nash games: 1) the Nash game model was solved with respect to both capacity and toll of the link 2; and 2) the Nash game model was solved with respect to toll, holding capacity constant. We then compared the results of these two scenarios. The comparison suggests that the welfare and profit losses were mostly due to the difference in the capacity of the border-crossing link F_2, while all the other decision variables are quite similar in the two scenarios.

Compared to the first best and second best scenarios, the Nash game whereby capacity was held constant resulted in lower welfare for both jurisdictions, while profit levels were higher than the first best scenario but lower than the second best scenarios where each jurisdiction maximized its welfare.

The global profit maximization scenario resulted in a lower F_2 than in all the other scenarios. Results from this analysis suggest that multi-jurisdiction collaboration on infrastructure provision could be challenging when profit maximization strategy is adopted. Competition on collecting tolls from non-residents (toll exporting) may suffocate interjurisdiction travel. This may be part of the reason why multi-jurisdiction P3 projects are rare in reality.

The analysis presented in this study is meant to serve as the foundation for future studies. The model can be extended to examine more realistic policy scenarios. First, we would like to evaluate the outcome of a scenario where the public agency and the private firm split the share equally. Second, the link 2 can be invested and operated by the private firm seeking profit maximization, while the other links can be operated by the public agencies to maximize user surplus and its share of the revenue on the link 2. Third, a fixed amount of payment will be paid to the private firm (availability payment arrangement), while the social welfare is maximized. We also intend to continue the analysis to examine more nuanced scenarios, such as the case of the Ohio River Bridges project, where one state formed a P3 while the other state used the traditional delivery model of procurement. Additionally, restrictions imposed by the public sector (e.g. price ceiling on the toll) can be explicitly included in the model. A more realistic financial model, rather than a mere profit function, could be proposed in order to investigate the factors that drive behaviors of not just private contractors and concessionaires but also investors.

Furthermore, we would like to extend the model from the stylized network in this study to be applied to a real world network. Relaxing some of the other assumptions, such model extensions might be able to provide context specific insights to assist policy makers in their decision making process.

States are increasingly resorting to the P3 approach to continue investing in surface transportation infrastructure that is vital for achieving their economic development objectives. In an era when a regional economy extends beyond some states' boundaries, the fact that the potentially powerful P3 approach has rarely been employed for cross-border transportation facility projects may be undermining the potential of the regional economy. The analysis in this study suggests there is room for additional research on the subject.

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