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U.S. HIGHWAY PRIVATIZATION AND HETEROGENEOUS PREFERENCES

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U.S. HIGHWAY PRIVATIZATION AND MOTORISTS' HETEROGENEOUS PREFERENCES

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Abstract: *We assess the welfare effects of highway privatization accounting for government's behavior in setting the sale price, firms' strategic behavior in setting tolls in various competitive environments, and motorists' heterogeneous preferences for speedy and reliable travel. We conclude motorists can benefit from privatization if they are able to negotiate aggressively with a private provider to obtain tolls and service that align with their varying preferences. Surprisingly, motorists are likely to be better off negotiating with a monopolist than with duopoly providers or under public-private competition. Toll regulation may be counterproductive because it would treat motorists as homogeneous.*

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Introduction

U.S. highways are experiencing a "perfect storm:" traffic congestion and delays are imposing ever greater costs on motorists and shippers; poorly maintained roads and bridges continue to damage vehicles and pose threats to travelers' safety; and for the first time since the Highway Trust Fund was created in 1956, the portion that finances federal highway expenditures is running a deficit.[1]

The road system's poor service quality and growing financial problems can be attributed to inefficient government policies, including the failure to charge appropriate prices for congestion and pavement damage, suboptimal road design and maintenance practices, and regulations that increase production costs (Winston (2000)). Efficient policies that would improve the system's performance seem politically intractable because they would threaten long-standing subsidies to road users, rents to suppliers of highway capital and labor, and demonstration projects that improve politicians' re-election prospects.

After policymakers accepted the fact that their policies were responsible for creating significant inefficiencies in intercity transportation, they turned to markets for help by deregulating the intercity modes' economic operations. As it has become clear that the public sector needs a large infusion of money to maintain and expand the highway system, policymakers have turned to the private sector for assistance by forming so-called public-private partnerships (PPPs), where the government leases a road to a private investor(s) for a specified period.[2] These partnerships are business deals that are intended to provide budgetary relief to

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[1] Some money in the trust fund is allocated to public transit.

[2] Examples of PPPs include the Chicago Skyway, Indiana toll road, and the proposed Trans-Texas Corridor; high-occupancy-toll (HOT) lanes in California and Texas and that are currently

the government and yield an acceptable rate of return for the firms that invest in infrastructure subject to government regulations. At the same time, highway travel conditions may not necessarily improve, especially because the contract between the private firm and the government may be poorly structured and prevent efficient pricing (Engel et al. (2007)). A pure market solution—namely, highway privatization—would be less encumbered by the government and may result in faster and more reliable travel, but it may also produce a welfare loss from market power (Vickers and Yarrow (1991)).

In this paper, we present exploratory empirical evidence on the economic effects of highway privatization by developing a stylized model where responsibility for providing highway services is transferred from the public sector to a private firm(s). Given the intractability of reforming public provision and the limitations of PPPs, privatization—while representing dramatic institutional change—may be the only hope for operating and maintaining the nation's $2.5 trillion road system more efficiently. Privatization may also be timely because the U.S. road network is largely complete and vast, enormously expensive investments in new capacity, which arguably justified public ownership and management of the roads in the past, are not necessary.

We analyze our model using data from motorists' travel on a major highway in California. Although privatization is often thought to produce social benefits by improving production efficiency (Roland (2008)), we focus on whether it could benefit motorists by improving road pricing and service quality. We find that under certain conditions highway privatization can benefit road users and increase social welfare. The key to privatization's success is that road users have heterogeneous preferences for highway service—travel speed and

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being constructed in the Washington, D.C. metropolitan area; and the Dulles-Greenway private toll road.

reliability—and through negotiations on tolls a private operator(s) may be forced to respond to those preferences in ways that public highway authorities have not. Surprisingly, we conclude that motorists are likely to achieve a larger welfare gain negotiating with a monopoly operator than with duopoly operators or if the monopoly competed against a public operator. The importance of preference heterogeneity in generating benefits suggests that it would be inadvisable to subject private operators to price regulations, which typically treat consumers as homogeneous and discourage product differentiation.

Background Literature

Our assessment of privatization is based on travel on a major limited-access state highway in California used heavily by long-distance commuters, but it could also apply to a federal highway. The "price" of travel on most federal and state highways is the gasoline tax, which does not vary significantly with the level of traffic congestion.

Knight (1924) injected a constructive role for privatization by arguing that a private road would set an optimal congestion toll if it faced competition from an alternative free (public) road. Friedman and Boorstin (1951), early advocates of privatization, suggested that the government should account for unfair competition by rebating fuel tax revenues generated by motorists driving on the free road to the private road owner. Even if the rebate does not occur, Viton (1995) found that a private road would be financially viable when competing against a public road for most types of road users. Edelson (1971) qualified Knight's result by showing that it holds in the special case that all travelers—including those using a transit alternative to the private road—have the same value of time. If travelers differ in their value of time, the toll could result in too much or too little congestion. De Palma and Lindsey (2000, 2002) and Calcott and

Yao (2005) conclude that private operators have incentives to introduce time varying tolls in alternative competitive settings. In sum, previous literature suggests that highway privatization could lead to the adoption of congestion pricing, but pricing's efficiency and distributional effects are likely to depend on competitive alternatives to the private road, the heterogeneity of travelers' preferences, and how the government allocates gas tax revenues.

Although the evidence is circumstantial, recent assessments broadly suggest that highway production efficiency in the United States would improve if a private road operator replaced a public authority. Roth (2005) reports that officials in the U.S. Department of Transportation estimate federal regulations raise highway project costs 20-30 percent. Poole and Samuel (2008) find that the share of toll revenues consumed by operating and maintenance costs is 43 percent for U.S. public toll roads and 23 percent for U.S. private toll roads. There are examples of reasonably low-cost public toll roads with a high cost/revenue ratio because tolls have been too low (e.g., the West Virginia Turnpike has not increased its tolls since 1989); but there are also examples of private operators whose tolls have been kept down by government caps (e.g., the Indiana Toll Road).[3] Finally, evidence from emergency highway repairs following an earthquake in 1994 that destroyed a bridge on Interstate 10 in Santa Monica and a gasoline tanker crash in 2007 that severely damaged a freeway ramp in Oakland indicates that economic incentives substantially reduce the time it takes the private sector to complete highway projects.

It is debatable whether the public sector's cost of capital in highway services is higher or lower than the private sector's cost of capital. In any case, Congress has recently introduced two measures that could reduce a private highway firm's cost of capital. First, the Transportation Infrastructure Finance and Innovation Act of 1998 established a new federal credit program

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[3] We are grateful to Peter Samuel for this point.

under which the U.S. Department of Transportation may provide a private firm with taxpayer subsidized credit. Second, as part of the 2005 Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, state agencies that work with private highway firms may issue tax exempt bonds on behalf of the project.

Model

We consider a multiple-lane highway that is transferred fully or in part to a private firm(s). The highway can be partitioned into two parallel routes, $r1$ and $r2$, connecting the same origin and destination. A common example of the network is a carpool lane(s) and general purpose lane(s) that comprise highways in many U.S. metropolitan areas. Privatization could arise, for example, if as is often the case in California, the carpool lanes do not meet minimum federal standards requiring average peak-period speeds of 45 miles per hour and the state decides to allow a private firm to purchase the lanes, set prices, and presumably increase highway speeds. Competitive options include allowing the private firm to also purchase the general purpose lanes (monopoly); allowing a different private firm to purchase the general purpose lanes (duopoly); and allowing the government to operate the general purpose lanes as a free road or a toll road (public-private competition).

In the cases of monopoly and duopoly we draw an analogy from certain shippers who organized into bargaining units following surface freight deregulation (Winston (1998)), and improve consumers' bargaining power (and welfare) by allowing a third party, such as the American Automobile Association, to negotiate contracts with a private highway operator to determine tolls for road users. Because a bilateral monopoly arises, we consider a range of toll outcomes.

Privatization therefore consists of the government selling, not leasing, one or both routes to a private firm(s) for a one time payment to the government with all risk transferred to the firm(s). Government determines the highway's sale price and we explore the effects of alternative assumptions about government's behavior. A private highway owner(s) is assumed to set profit maximizing tolls or tolls that are determined through bargaining. We do not consider the contracting problems that have been identified in public-private partnerships, where private firms bid to operate a highway for a fixed period of time. Engel et al. (2001) have developed a "least present value auction," where the firm that proposes the lowest present value of revenues is given the highway franchise and allowed to collect toll revenues until that present value is reached. The franchise then ends and the roads revert to the public sector. Engel et al. (2003) point out that renegotiation of highway franchises reduced their benefits in Latin America, and Engel et al. (2006) argue that franchise contracts for private toll roads in the United States during the 1990s were flawed because they did not adapt to demand realizations.

Turning to road users, we capture their heterogeneous preferences for highway services by using a demand model that accounts for the variability in the value of travel time and travel time reliability. Motorists are assumed to make the discrete choice of whether to travel and conditional on traveling, to make the discrete choice of route ($r1$ or $r2$) and vehicle occupancy (solo driving or carpooling) that maximizes the utility of their trips. Finally, because a federal trust fund is not necessary to finance (private) roads, we consider the effects of suspending (or simply rebating) the state and federal gasoline tax that motorists pay when both routes are privatized. Apparently, Arizona's 1991 private tollways law was the first to offer motorists the opportunity to receive a refund of gasoline taxes paid for miles driven on a private tollway. In what follows, we develop our empirical specification of highway demand, travel time and production costs, and equilibrium.

Demand. Let Ω={0,1,…,J} denote the choice set facing a potential road user, where alternative 0 is the outside choice of not traveling and alternatives 1–J represent the different combinations of routes and vehicle occupancy.

The utility of individual *i* choosing alternative 0 is:

$$U_{i0} = \delta_0 + \varepsilon_{i0} \quad , \tag{1}$$

where the traveler's utility from not traveling is divided into a mean δ_0, which is constant for all motorists, and a random deviation ε_{i0}. The utility of individual *i* choosing alternative *j* is:

$$U_{ij} = \alpha_i P_j + \eta_i T_j + \phi_i R_j + X_j B_i + \varepsilon_{ij}\, , j>0 \; , \tag{2}$$

where P_j is the price of the alternative and α_i is the individual's preference for price; T_j is the travel time of the alternative and η_i is the individual's preference for travel time; R_j is the travel time uncertainty of the alternative and ϕ_i is the individual's preference for time uncertainty; X_j is a vector of observed exogenous attributes of alternative *j* and B_i are the individual's preferences for those attributes; and ε_{ij} is a random deviation that is independent of the observed attributes.

We assume N potential travelers consider using the highway. Each individual *i* in the sample is drawn from this population. To account for the heterogeneity in travel preferences, we assume the coefficients of equation (2) are normally distributed, conditional on an individual's observed profile denoted by Z_i; hence,

$$\Theta_i \equiv \left(\alpha_i, \eta_i, \phi_i, B_i\right)' \sim N\left(Z_i \gamma, \Sigma\right), \tag{3}$$

where Σ is a diagonal variance matrix, and $\boldsymbol{\gamma}$ is a vector of parameters to be estimated.

We specify the joint distribution of $\varepsilon_i \equiv (\varepsilon_{i0}, \varepsilon_{i1}, ..., \varepsilon_{iJ})$ by the Generalized Extreme Value distribution; thus, the market share of an alternative has the nested-logit form where all the travel choices (route and vehicle occupancy) are in one nest with a similarity parameter λ and the choice of whether to travel is in another nest. This specification captures the idea that the substitution pattern between any two travel choices is likely to be different from the substitution pattern between traveling and not traveling. Our mixed-logit specification for travel choices allows for various potential error correlation patterns among travel alternatives, which could arise from individual-specific preferences for travel features that are shared by particular alternatives.[4]

The preceding assumptions imply that the probability of an individual with observed characteristics Z_i choosing alternative *j* is given by:

$$S_{ij} = \int_{\Theta_i} S_{ij}(\Theta_i) \cdot f(\Theta_i | Z_i) d\Theta_i \, , \tag{4}$$

where $f(\Theta_i | Z_i)$ is the normal density function of Θ_i;

$$S_{ij}(\Theta_i) = \frac{e^{(\alpha_i P_j + \eta_i T_j + \phi_i R_j + X_j B_i)/\lambda}}{e^{\lambda D_i}} \cdot \frac{e^{\lambda D_i}}{e^{\delta_0} + e^{\lambda D_i}} \tag{5}$$

is the choice probability conditional on the values of the normal random variates, and

$$D_i = \ln \sum_j e^{(\alpha_i P_j + \beta_i T_j + \phi_i R_j + X_j B_i)/\lambda} \tag{6}$$

is the inclusive value of the travel choices. The probability of an individual choosing not to travel conditional on the values of the normal random variates is:

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[4] The mixed-logit model is a multinomial logit model with random parameters.

$$S_{i0}(\Theta_i) = \frac{e^{\delta_0}}{e^{\delta_0} + e^{\lambda D_i}}. \qquad (7)$$

The expected volume of traffic that is generated by individuals who choose a travel alternative j with vehicle occupancy O_j is $V_j \equiv \frac{\sum_{i=1}^{N} S_{ij}}{O_j}$.

Demand model parameters. The values of the parameters of the route-vehicle occupancy choice model (equation (2)) are obtained from Small, Winston, and Yan (2006), hereafter SWY. SWY conducted surveys in 1999 and 2000—a stable period of highway travel—to analyze motorists' behavior on California State Route 91, a major limited-access expressway used heavily by long distance commuters. A ten-mile stretch in Orange Country includes four free lanes and two express lanes in each direction. Travel times were obtained from field measurements at many different times of day, corresponding to the travel periods covered by the surveys.

Motorists who wish to use the express lanes must set up a financial account and carry an electronic transponder to pay a toll, which varies hourly according to a preset schedule. The cost of electronic toll collection is small. Carpools of three or more people could use the express lanes during the period of the surveys at a 50 percent discount. Unlike the regular lanes, the express lanes have no entrances or exits between their end points. SWY analyzed the determinants of three simultaneous decisions by motorists: 1) whether to acquire a transponder, which gives them the flexibility to use the express lanes whenever they desire; 2) whether to travel on the express toll or free lanes for their trip; and 3) how many people to travel with in their vehicle: solo, carpool with another person (HOV2), or carpool with at least two other people (HOV3). The three choices are assumed conditional on mode choice (car versus public transport), residential location, and time of day of travel. We discuss the possible effects of this assumption on our findings later.

We modify the SWY choice model for our purposes by setting the preference parameter for a transponder to zero because all travelers are assumed to have a transponder to travel on the tolled highway. We also set the preference parameter associated with lane choice to zero because the two routes under consideration are assumed to be homogeneous; travelers choose between them based on the toll, travel times, and travel time uncertainties.

The coefficients of the utility function based on motorists' choices among six alternative combinations of route (free or tolled) and vehicle occupancy (solo, HOV2, or HOV3) are shown in table 1.[5] The toll (price) coefficient enters the specification separately and is interacted with household income; travel time, measured at the median value, is interacted with a cubic function of trip distance; and travel time uncertainty, measured as the difference between the 80th and 50th percentiles of the distribution of travel times, enters separately.[6] The interactions for the toll and travel time variables capture observed heterogeneity among travelers. The HOV2 and HOV3 dummies indicate (negative) preferences for carpooling, and additional observed heterogeneity is indicated by interactions among certain socioeconomic characteristics and a carpool dummy. Finally, the model captures unobserved heterogeneity with random coefficients, assumed to be

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[5] The coefficients are from table 3 of SWY but rescaled using the scale parameter of the Brookings RP (revealed preference) sample, which is used in our simulations.

[6] SWY found that measuring travel time uncertainty as the difference between the 80th and 50th percentiles produced a more accurate fit of the model than did alternative measures such as the standard deviation.

normally distributed, for travel time, travel time uncertainty, and the HOV2 and HOV3 dummies.[7]

The value of travel time (VOT) and value of reliability (VOR) are the ratios of the marginal utilities of travel time and travel time uncertainty to the marginal utility of money cost. Given our specification of utility in equation (2), the values are expressed as

$$VOT = \frac{\eta_i}{\alpha_i} \tag{8}$$

$$VOR = \frac{\phi_i}{\alpha_i}\ . \tag{9}$$

Small and Verhoef (2007) report from a survey of mode choice models that a reasonable average VOT is 50 percent of the gross wage, while Miller (1989) finds an average value from a survey of route choice models that is closer to 60 percent of the gross wage. Small and Verhoef point out that VOT estimates vary from roughly 20 to 100 percent of the gross wage. Table 2 presents VOT and VOR estimates and shows that motorists' median values can be interpreted as being close to the high end of previous estimates of VOT, indicating that highway service quality is important to them. At the same time, motorists exhibit a wide range of preferences for speedy and reliable travel, as the total heterogeneity in the value of time and the value of reliability (uncertainty) is roughly aligned with or exceeds the corresponding median value.

We also need to calibrate the three parameters that are relevant to the outside choice of whether to travel: the population size of potential travelers (N), the mean utility of the outside choice (δ_0), and the similarity of the travel choices (λ). An additional matter is that private

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[7] Brownstone and Train (1999) show how such a structure mimics a generalized extreme value model that is analogous to a generalized nested logit model with error terms for groups of alternatives with different car occupancies (solo, HOV2, HOV3) that are correlated with each other.

highways are assumed to be funded solely by toll revenues. Currently, U.S. highways are mainly funded by federal and state gasoline taxes, averaging $0.49 per gallon. We assume that motorists do not have to pay those taxes when the highway is privatized, which is equivalent to assuming a 10%-15% decrease in gasoline prices at their recent level of roughly $4.00 per gallon. In the context of our nested-logit model, where travelers first decide whether to travel and then choose a route-vehicle occupancy alternative, lower gasoline prices mainly affect the decision of whether to travel and can therefore be captured by expanding the specification of the parameter δ_0 in the choice model.

We specify δ_0 as a linear function of a motorist's driving cost (E), which includes fuel costs as the main component:

$$\delta_0 = \bar{\delta} + \hat{\delta} \cdot E . \tag{10}$$

The average cost of driving in the U.S. is about $0.40 per mile (Langer and Winston (2008)). Given the average gas mileage for new and used vehicles in the United States is about 15 to 17 miles per gallon (www.nhtsa.gov), elimination of the gasoline tax implies that driving costs would decline $0.03 to $0.04 (per mile) or roughly 10%.

To calibrate the four parameters $(N, \lambda, \bar{\delta}, \hat{\delta})$, we follow SWY and choose a value of λ as small as possible without causing numerical instability because we expect the travel alternatives to be much closer alternatives to each other than to not traveling.[8] We calibrate the other parameters to generate travel conditions that are consistent with previous evidence on travel conditions on SR 91: namely, travel times on the free (untolled) lanes are 20 minutes; the elasticity of travel with respect to the full cost of travel (including the toll and the value of travel

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[8] We set λ =0.2 and found in sensitivity tests that alternate values did not have much effect on the main findings.

time and unreliability) is -0.36; and the elasticity of travel with respect to the driving costs is -0.3.[9]

Costs. The cost side of our model consists of travelers' time costs and the private firm's production costs. Travel time on route $r \in (r1, r2)$ is determined by the Bureau of Public Roads formula used by many researchers:

$$T_r = t_f L_r \left(1 + 0.15 \left(\frac{V_r}{K_r} \right)^4 \right), \tag{11}$$

where T_r is the travel time on route r; t_f is the travel time per-mile under free-flow conditions; L_r is the length of the route r; $V_r \equiv \sum_{j \in \Omega_r} V_j$ is the traffic volume on route r and Ω_r is the subset of travel choices involving travel on route r; and K_r is the capacity of the route.[10] As in SWY, we measure travel time uncertainty on route r by treating it as a constant fraction of travel time delay (travel time minus free-flow travel time) where the fraction is determined from actual travel on the free lanes averaged over 5:00a.m. to 9:00a.m.:

$$R_r = 0.3785 \cdot T_r . \tag{12}$$

A private firm's production costs include the initial costs to acquire the highway from the government and the costs to operate and maintain the infrastructure. The marginal (production) cost incurred by motor vehicles is mainly reflected in pavement damage. According to the U.S. Federal Highway Administration (2000), the marginal pavement damage cost for automobile

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[9] The driving cost elasticity of -0.3 is consistent with long-run estimates reported in Mannering and Winston (1985); the short-run driving cost elasticity estimate is roughly -0.2. Sensitivity analyses indicated that are our central findings are not particularly sensitive to the assumed values of the elasticities.

[10] Our findings were not particularly sensitive to assuming powers of the volume-capacity ratio that were somewhat higher or lower than four.

traffic on an urban interstate highway is $0.001 per vehicle mile. We do not include heavy trucks in this analysis, but it is useful to note that their marginal pavement damage costs range from $0.01 per vehicle mile to $0.40 per vehicle mile, depending on the truck's weight and axle configuration. Based on the evidence summarized earlier, we assume that pavement maintenance costs are reduced 20% under privatization and we specify the private firm's operating cost (C) as:

$$C = F + 0.0008\sum_r V_r L_r \,, \tag{13}$$

where F is the fixed component of operating cost.

To facilitate our simulations, it is useful to express operating profits, measured as the difference between toll revenues and operating costs, as a percentage of toll revenues. As noted, Poole and Samuel (2008) find, on average, that operating costs account for 43% of U.S. public toll roads' revenues. Assuming operating costs would fall 20% under privatization indicates that 65% of toll revenues constitute operating profits for a private highway firm.[11]

The initial cost of the road (I)—that is, the purchase price set by the government—affects the private firm's decision of whether to buy the highway. When a private firm can own and operate the highway for only a finite period—as is the case for firms participating in recent public-private partnerships—the firm may not be able to raise sufficient revenues during the franchise term to recover the initial cost. In our analysis, the road is already built and we assume that the private operator owns and operates the highway forever. We do not make assumptions about how the private operator finances the purchase of the road or about the interest rate that is

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[11] This figure may be conservative because Poole and Samuel report that operating costs account for roughly 25% of toll revenues of private highway operators in the United States and in other countries.

paid. Formally, a private firm is willing to buy the highway if the present discounted value of lifetime operating profits (PVP) covers the initial cost of acquiring the infrastructure:

$$\sum_{t=0}^{+\infty} \delta^t \pi_t = PVP \geq I \,, \tag{14}$$

where δ is the discount factor and π_t is the operating profit at time period t.

Equilibrium. The objective of a private highway operator is to charge prices (tolls) that maximize the present value of its future profits. Because current pricing decisions are not likely to affect future decisions, we can express the dynamic problem as a series of identical static problems and express equation (14) as $(1-\delta)^{-1}\pi \geq I$.[12]

The analysis of highway privatization can be formulated as a sequential-moves game: in the first stage, the government sets the price to sell the infrastructure; in the second stage, the operator sets prices and capacity allocation to maximize its objective; in the third stage, travelers choose alternatives to maximize their utilities given road prices and those choices determine highway travel times and travel time uncertainties. Equilibrium of the game is then a *subgame perfect equilibrium* (SPE) and we characterize it by backward induction.

Because the number of travelers is large, each traveler behaves as both a price taker and a traffic flow taker. Thus, the equilibrium of the subgame at the third stage is a *Wardrop Equilibrium* (Wardrop (1952)), which can be obtained as the limit of a sequence of *Nash Equilibira* of games as the number of players goes to infinity (Haurie and Marcotte (1985)).

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[12] It is possible that current pricing decisions may affect future ones through reputation effects. For example, operators might develop reputations for "price gouging" and motorists would develop habits to avoid those roads. But reputation effects are not likely to arise in the cases that we analyze here that involve some form of competition, such as private duopoly, because the two routes are perfectly substitutable and motorists do not incur costs from switching from one route to the other. Reputation effects could develop in the monopoly case, but we also consider bilateral long-run price negotiations between users and the monopolist to limit monopoly power.

Denote p_j as the price of alternative *j* and $p \equiv (p_1, ..., p_J)$ as the price vector; the market share vector $S^*(p) \equiv (S_1^*(p), ..., S_J^*(p))$ denotes the Wardrop Equilibrium given $p \geq 0$. In the appendix, we show that a unique Wardrop Equilibrium exists for a price vector $p \geq 0$.

Policy and Competition Scenarios

We consider government policies to sell the road to the private sector with and without regulation and policies to allow different forms of highway competition with and without negotiations between the operator(s) and motorists.

Highway Privatization with Toll Regulation

We begin with a scenario, motivated by Engel et al. (2001), where the government chooses a toll when it sells the infrastructure to a private firm and the private firm is compensated with the toll revenues. In our two-route network, government regulation is assumed to take the form of a uniform toll and the price of alternative *j* is obtained by dividing the toll by vehicle occupancy. The government seeks to maximize social welfare given by the sum of consumer surplus and the private firm's operating profits:

$$W(p) = CS(p) + \pi(p) \quad , \tag{15}$$

where we do not include the subscript *r* for route, $\pi(p)$ denotes the operating profits accruing to the private operator at the Wardrop equilibrium given the toll, and $CS(p)$ is the expected change in consumer surplus relative to the base case of no-toll. Consumer surplus is defined by the log-sum rule for nested logit (Choi and Moon 1997)

$$CS(p) = \sum_i \int_{\Theta_i} \frac{1}{\tau_i} \Delta \left\{ \ln \left[e^{\delta_0} + e^{\lambda D_i} \right] \right\} \cdot f(\Theta_i | Z_i) d\Theta_i \, , \tag{16}$$

where τ_i is the individual's marginal utility of income determined from the coefficient of the price variable in equation (2) using Roy's identity, D_i is the inclusive value given in equation (6) with travel times and travel time uncertainties at the Wardrop Equilibrium given the toll, and $\Delta\{\cdot\}$ indicates the difference of the term in brackets when the equilibrium price (toll) is p and when it is zero.

The government chooses a sales price I and a toll p that maximizes the present value of welfare subject to the firm purchasing the highway, referred to as the firm's participation constraint, and the government satisfying a politically acceptable reservation price, I^0, assumed to cover construction costs and referred to as the government's participation constraint:

$$\max_{I,p} \sum_{t=0}^{+\infty} \delta^t W(p) = \frac{W(p)}{1-\delta} \tag{17}$$

$$s.t.\ \frac{\pi(p)}{1-\delta} - I \geq 0$$

$$I \geq I^0.$$

Given these constraints, the actual toll could deviate from the optimal congestion toll p^*.

To further the analysis, we follow Laffont and Tirole (1993) and Engel et al. (2001) and assume that the marginal welfare gain of a dollar to travelers is greater than the marginal welfare gain of a dollar to the private operator. Accordingly, the government would like to redistribute the private operator's rents (excess operating profits) to the travelers in lump sum. Therefore when $\frac{\pi(p^*)}{1-\delta} - I^0 > 0$, the government sets the toll as the optimal congestion toll and its sale price satisfies $\frac{\pi(p^*)}{1-\delta} - I = 0$ (that is, the present value of the private firm's operating profits covers its cost of purchasing the road); when $\frac{\pi(p^*)}{1-\delta} - I^0 \leq 0$, the government's sale price is I^0 and the toll is the solution to the constrained optimization problem in equation (17) given that the operator's participation constraint is binding at I^0. The solutions for I and p along with the Wardrop equilibrium given the toll constitute the SPE to the overall game.

Given the government's welfare "weights," a simpler approach it could take is to define welfare solely in terms of consumer surplus and to determine the welfare maximizing toll and sales price subject to the firm's and its participation constraints.

Highway Privatization without Toll Regulation

Government regulation of tolls may be justified to curb market power but such regulation may turn out to be unnecessary and may undermine the potential gains from privatization by impeding product differentiation of the two routes. We therefore analyze models that allow tolls to be determined in various competitive environments and that may vary by route. Again, the government chooses a sale price to transfer the highway to a private operator(s) and that price is aligned with the competitive environment—that is, we assume the government sets the price to extract the private operator's excess operating profits under market outcomes subject to the government's participation constraint. The private operator then allocates capacity between the two routes and sets tolls to maximize its profits given the sale price. We consider the following competitive situations.

Monopoly provision. Both routes are sold to a private firm that determines how road capacity is allocated (K_{r1}, K_{r2}) and charges prices (p_{r1}, p_{r2}) to maximize profits. The firm's one-period operating profit function is

$$\pi(K_{r1}, K_{r2}, p_{r1}, p_{r2}) = \sum_{m \in (r1, r2)} V_m(K_{r1}, K_{r2}, p_{r1}, p_{r2}) \cdot p_m - C(K_{r1}, K_{r2}, p_{r1}, p_{r2}) \, , \qquad (18)$$

where $V_m(K_{r1}, K_{r2}, p_{r1}, p_{r2})$ is the traffic volume and $C(K_{r1}, K_{r2}, p_{r1}, p_{r2})$ is the firm's operating cost at the Wardrop equilibrium given the tolls and capacity allocation. Given the government's sale price, the firm solves

$$\max_{(K_{r1}, K_{r2}, p_{r1}, p_{r2})} \sum_{t=0}^{+\infty} \delta^t \pi(K_{r1}, K_{r2}, p_{r1}, p_{r2}) = \frac{\pi(K_{r1}, K_{r2}, p_{r1}, p_{r2})}{1-\delta} \tag{19}$$

$$s.t.\ \frac{\pi(K_{r1}, K_{r2}, p_{r1}, p_{r2})}{1-\delta} - I \geq 0$$

$$K_{r1} + K_{r2} = K$$

where K is total capacity of the highway. Without the participation constraint, the firm obtains the monopoly profit-maximizing solution denoted by $\left(K_{r1}^M, K_{r2}^M, p_{r1}^M, p_{r2}^M\right)$.

As noted, the government's sale price seeks to extract excess operating profits. Thus, if $\frac{\pi\left(K_{r1}^M, K_{r2}^M, p_{r1}^M, p_{r2}^M\right)}{1-\delta} - I^0 > 0$, the sale price satisfies $\frac{\pi\left(K_{r1}^M, K_{r2}^M, p_{r1}^M, p_{r2}^M\right)}{1-\delta} - I = 0$; otherwise, the government's sale price is I^0 and the monopoly's allocation of capacity and tolls satisfy equation (19) given the participation constraint $\frac{\pi(K_{r1}, K_{r2}, p_{r1}, p_{r2})}{1-\delta} = I^0$. The sale price, profit-maximizing solutions from equation (19) given the sale price, as well as the Wardrop equilibrium given the profit-maximizing solutions constitute the SPE to the overall game.

The problem in equation (19) assumes that travelers have no negotiating power in setting tolls; thus, solutions of the problem represent an upper bound for tolls under monopoly provision. A more general formulation recognizes that tolls could be set through negotiations between travelers, represented by a third party such as the American Automobile Association, and the firm. We consider an outcome as a bargaining solution if both the private operator and travelers are, on average, not worse off compared with the base case of no-toll.

Two extreme outcomes of the bargaining solution exist. In the *operator's solution*, the monopolist maximizes profits subject to the additional constraint that the change in consumer surplus is nonnegative. In the *travelers' solution*, travelers maximize consumer surplus subject to the firm earning non-negative profits. A bargaining solution may include or lie between those extreme cases and can be expressed as the solution to the problem in equation (19) with the additional consumer surplus constraint that $CS(K_{r1}, K_{r2}, p_{r1}, p_{r2}) \geq s$, where $s \in [0, \bar{s}]$ represents the travelers' bargaining power and its upper bound, $\bar{s}$, is the change in consumer surplus in the travelers' solution.

Let $(K_{r1}^B, K_{r2}^B, p_{r1}^B, p_{r2}^B)$ denote the bargaining solution without the operator's participation constraint. If $\frac{\pi(K_{r1}^B, K_{r2}^B, p_{r1}^B, p_{r2}^B)}{1-\delta} > I^0$, the government's optimal sale price of the highway satisfies $\frac{\pi(K_{r1}^B, K_{r2}^B, p_{r1}^B, p_{r2}^B)}{1-\delta} = I$; if $\frac{\pi(K_{r1}^B, K_{r2}^B, p_{r1}^B, p_{r2}^B)}{1-\delta} \leq I^0$, the government's sale price is I^0 and the solution to the bargaining outcome forces the operator's participation constraint to be binding at I^0.

Duopoly provision. In this scenario, the highway is partitioned into two routes with equal capacities that are operated by competing private firms and we assume that the government cannot sell the routes to the firms at different prices; that is, $I_{r1} = I_{r2}$.[13]

When the two routes are simultaneously privatized such that the firms engage in Bertrand competition, the operator of route $r1$ solves:

$$\max_{p_{r1}} \sum_{t=0}^{+\infty} \delta^t \pi_{r1}(p_{r1}, p_{r2}) = \frac{\pi_{r1}(p_{r1}, p_{r2})}{1-\delta} \tag{20}$$

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[13] Little capacity of SR 91 in California was lost when it was partitioned into two routes, one consisting of free lanes and the other consisting of toll lanes.

$$s.t.\ \frac{\pi_{r1}(p_{r1},p_{r2})}{1-\delta}-I_{r1}\geq 0$$

$$I_{r1}\geq I_0/2\,.$$

The solution to the problem, denoted by $p_{r1} = f_{r1}(p_{r2})$, is the toll schedule with respect to p_{r2}. The operator of route $r2$ solves:

$$\max_{p_{r2}}\sum_{t=0}^{+\infty}\delta^t\pi_{r2}(p_{r1},p_{r2})=\frac{\pi_{r2}(p_{r1},p_{r2})}{1-\delta} \tag{21}$$

$$s.t.\ \frac{\pi_{r2}(p_{r1},p_{r2})}{1-\delta}-I_{r2}\geq 0$$

$$I_{r2}\geq I_0/2\,.$$

The solution to the problem, denoted by $p_{r2} = f_{r2}(p_{r1})$, is the toll schedule with respect to p_{r1}. The Bertrand-Nash equilibrium of duopoly price competition is determined by the intersection of the two best-response functions.

The government may also privatize the two routes sequentially. Without loss of generality, we assume that route $r2$ is sold first. The operator of $r2$ then sets a toll and commits to it. The two firms then engage in Stackelberg price competition. The operator of $r1$ solves the problem given in equation (20) by choosing the profit-maximizing toll given the price on route $r2$. The operator of route $r2$ then solves the problem in equation (21) with the additional constraint that $p_{r1} = f_{r1}(p_{r2})$.

We denote the equilibrium prices of duopoly competition (either Bertrand or Stackelberg) by $\left(p_{r1}^D, p_{r2}^D\right)$ and note that in equilibrium the participation constraints of both firms are satisfied. When the operators' present value of operating profits exceeds the government's reservation price, the government sets the sale price such that the firm with the lowest operating profit breaks even in equilibrium; otherwise the sale price is the reservation price $\left(I_{r1} = I_{r2} = I_0/2\right)$ and the duopoly equilibrium is determined by the solutions to equations (20) and (21) given the reservation price is a binding participation constraint.

We can also account for bargaining under duopoly competition. In the operators' solution, given the toll of the other operator, each operator chooses the profit maximizing toll subject to a non-negative change in consumer surplus. In the travelers' solution, given the toll of the other operator, each operator sets the toll to maximize the change in consumer surplus subject to earning non-negative profits.

Public-private provision. The final competitive scenario we consider allows the government to compete with a private provider. The government's objective is to maximize net benefits that are composed of consumer surplus and its budget balance. The government does not explicitly concern itself with the private operator's profits; it assumes that the private operator makes profit-maximizing decisions.

The private firm purchases one of the routes and the government continues to operate the other route (without loss of generality, we assume that route $r1$ is privatized). The government first determines the capacity to privatize (K_{r1}); its sale price seeks to extract the private firm's excess operating profits and it cannot be lower than the reservation price level. Price competition evolves in two alternative ways: 1) the private and public operators set tolls simultaneously; 2) the government sets the toll on route $r2$ first. Both cases correspond to those in private duopoly competition with the only differences that the public operator's objective is to maximize net benefits, as defined above, and it does not face the participation constraint because it does not have to purchase its route. We assume that the government eliminates the gas tax, but we also consider the case where the government continues to charge a gasoline tax and does not charge a toll on its portion of the highway.

Investment decisions under privatization. Thus far, we have assumed that the capacity of the privatized highway is fixed. But as traffic continues to grow, the private operator may wish to expand capacity by building an additional lane. We can determine the competitive conditions under which such expansion is likely to occur and the economic effects. The median cost to build a lane-mile in the United States is roughly $2 million (Washington State Department of Transportation (2002)). Given this figure and the other empirical parameters, the private operator will add another lane if the present value of operating profits from doing so minus the construction costs exceeds the present value of operating profits before the capacity was expanded.

Findings

In the simulations, we make the standard assumption that road capacity is 2,000 vehicles per lane per hour, which yields 12,000 vehicles per hour for the six-lane one-directional freeway under consideration. In the base case scenario, we assume no tolls are charged and that travel time on the highway is 20 minutes implying a speed of 30 miles per hour, which is approximately the travel speed on the SR91 free lanes during the afternoon rush hour. Based on our equilibrium model of the government's sale of the highway and private firm(s)' supply of and motorists' demand for highway services, we simulate the economic effects of alternative privatization scenarios. For each, we calculate the highway's sale price, tolls, travel times, choice shares, the annual and present value of operating profits, and the change in the government's budget, consumer surplus, and social welfare.[14] The change in the government's budget accounts for the revenues it receives from selling the highway, the maintenance cost savings, and the loss in gasoline tax revenues, and the changes in all the welfare components are expressed per potential highway user (*N*). Finally, we report our main findings as single-period outcomes because, as noted, our dynamic formulation can be analyzed as a series of identical static problems.

Highway Privatization with Toll Regulation

A pure highway privatization policy without any government regulation represents a dramatic shift in policy that may encounter political resistance because of concerns that the private operator would exercise market power; thus, it is useful to determine whether regulation might be a necessary concomitant of privatization. In our analysis, government regulation consists of setting a uniform toll to maximize consumer surplus and operating profits or to only maximize consumer surplus. It is reasonable to assume that a drawback of government regulation is that it would impose a uniform toll and inhibit differentiated tolls. Indeed, one of economic deregulation's major benefits was that firms were able to introduce price-service packages, which had been prohibited under regulation, to cater to different types of consumers (Winston (1998)).

Table 3 shows that the government can raise welfare by privatizing the road and imposing regulation. But as we have learned from the public sector's reluctance to adopt congestion pricing, any proposed change in highway policy is unlikely to gain widespread political support if, on average, it harms motorists. Motorists are able to gain if tolls are set to

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[14] Operating profits are determined as 65% of the toll revenues (Poole and Samuel (2008)). We assume a 4.5% discount factor, which is consistent with recent long-term interest rates, to express the present value of operating profits.

maximize consumer surplus because the improvement in travel time and the rebate or elimination of gasoline taxes exceeds the modest toll. The breakeven level of the toll is consistent with the government selling the road to the private operator at its reservation price of $12 million per mile, which covers the median per-mile construction costs of six-lanes accommodating traffic in one direction.

When the government seeks to maximize consumer surplus and operating profits, it sells the road to the private highway operator for a higher price, $49.4 million per mile, and sets a much higher toll that enables the private operator to break even.[15] Hence, motorists' benefits from improved travel times and the gas tax rebate fall short of their loss from the toll, although the higher toll is associated with greater improvement in the government budget and a larger increase in social welfare.

In sum, if the government privatizes the highway but is responsible for regulating the toll, it must sacrifice one-fourth of the gains in social welfare to enable motorists to benefit from the policy. Because we have indicated that motorists vary significantly in their preferences, it is natural to ask if regulation—which prevents price and service offerings from responding to preference heterogeneity—is necessary for motorists to benefit from privatization or could motorists and society realize larger gains without regulation because prices and service might be better aligned with motorists' preferences through bilateral negotiations.

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[15] The estimated sales price appears to be consistent with the $40 million per mile received by the state of Indiana for the sale of its toll road and considerably below the $200 million per mile received by the city of Chicago for the sale of its skyway.

Highway Privatization without Toll Regulation

We now examine competitive scenarios where the private operator instead of the government is responsible for setting the toll and, as noted, the sale price varies with the competitive environment.[16]

Monopoly. As shown in table 4, we find that privatization reduces social welfare because the highway operator maximizes profits by setting a very high toll that significantly reduces travel times, but significantly increases the share of motorists who do not travel on the road. The improvement in the government's budget fails to offset the loss in consumer surplus and the monopolist has little incentive to differentiate highway services, which would benefit users given their heterogeneous preferences, because traffic is substantially reduced.[17] In fact, most motorists who continue to use the highway form carpools.

Privatization could potentially gain public support by benefiting motorists—even without explicit regulation of the monopolist's tolls—if policymakers encourage motorists and the highway operator to negotiate prices. For example, certain railroad shippers have been able to obtain lower prices by organizing into a bargaining unit and allowing a third-party logistics firm to negotiate prices for them (Winston (1998)). A similar practice could develop in a private highway market, where motorists are represented by a firm or association that negotiates tolls with the private operator.[18]

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[16] The government's sale price affects the private operator's toll only when it is binding at I_0.

[17] When the capacity of the two routes is allocated equally, the monopolist maximizes its profits and the difference between the profit maximizing tolls on the two routes is only about $0.002. Verhoef and Small (2004) also find that a private monopoly operator differentiates tolls very little.

[18] The framework could be expanded to allow all road users, including truckers, government services, and motorists, to be represented by an agent who negotiates tolls on their behalf.

As noted, two polar bargaining outcomes exist: the travelers' solution and the operator's solution. In the travelers' solution, tolls and the allocation of highway capacity are set to maximize consumer surplus subject to the private operator earning non-negative profits. The central result shown in column 3 is that compared to privatization with regulation, privatization without regulation significantly increases the benefits to motorists and society by differentiating tolls and service on the two routes: 5 lanes become express lanes with a toll of $2.19 and a travel time of 17.6 minutes and the other lane has no toll and a travel time of 34.4 minutes. Consumer surplus turns positive, on average, because travelers with higher values of travel time and reliability can pay a modest toll to use the faster lanes and travelers with the lowest values can continue to use the free lane, not pay the gas tax, but face a marked increase in travel time over the current situation. Because even those motorists who use the free lane may wish to use the express lanes on particular days when they are anxious to reach their destinations, the benefits to motorists from privatization are likely to be broadly shared.[19] An interesting feature of the results is that travel on the faster route still moves considerably more slowly than a free-flow speed. This is consistent with findings obtained by Small and Yan (2001), which indicate that when one route is essentially free, the other is best priced to allow some congestion, but contrasts with current pricing on most high-occupancy-toll (HOT) lanes that set prices to approximately generate free-flow speeds.

Motorists' welfare, on average, is unchanged under the operator's solution shown in column 4 but tolls and service are even more sharply differentiated on the two routes and the overall gain in welfare is higher than in the travelers' solution. The latter occurs because the

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[19] Descriptive data summaries indicate that many motorists pay to use the express toll lanes on California SR 91 one or two days a week. This behavior makes it difficult to calculate an accurate distribution of driver benefits by, for example, income level.

monopolist pays a much higher price for the road, thereby significantly improving the government's budget.

Of course, by the time a privatization policy is implemented, the growth in traffic will result in delays that are greater than they are today. Under such conditions, tolls become even more essential to allocate scarce highway capacity. The last three columns of the table indicate that privatization's benefits to motorists and social benefits increase if we assume the population of potential travelers grows 20 percent, which generates additional congestion. It is interesting that the travelers' solution yields a much more differentiated toll in response to greater congestion and produces a social welfare gain that now exceeds the gain produced under the operator's solution.

Because it is unlikely that negotiations between motorists and the private operator would result in a polar outcome, it is fortunate that a wide range of negotiating outcomes could enable both the private operator and motorists to gain from privatization thereby enhancing the feasibility of the policy. Figure 1 shows the tradeoffs under different allocations of highway capacity and finds that the potentially largest "win-win" outcomes occur when highway service is differentiated by a price-service package of one route consisting of 5 lanes and another route consisting of one lane. Given this allocation of capacity, figure 2 shows the feasible tradeoffs of tolls and consumer surplus on the two routes, and figure 3 shows the feasible tradeoffs of consumer surplus and the sale price of the highway.

Duopoly. Policymakers may be concerned about allowing a monopolist to provide highway services and may be willing to support privatization only if duopoly highway competition can be created. We initially assume that the highway consists of two equal capacity routes each operated by a private operator and that the gas tax is rebated. We further assume that the government does not sell the routes to the operators at different prices and is able to extract the excess operating profits only from the duopolist earning the lowest profits, potentially enabling the other duopolist to earn excess operating profits.

As shown in table 5, duopoly competition (Bertrand) sharply reduces tolls from monopoly provision, reduces the loss to motorists, and improves welfare.[20] In the appendix, we present graphical solutions that show the equilibria under duopoly competition.

Although a highway duopoly reduces motorists' welfare loss from monopoly provision, it does not enable them to gain directly from highway privatization; thus, we explore the effects of allowing motorists and the duopolists to negotiate tolls (graphical solutions of duopoly equilibria under bargaining are also shown in the appendix). We present the travelers' solution in column 3 and find that motorists now gain because highways offer differentiated prices and service that maximizes consumer surplus subject to the operators breaking even. But because the duopoly operators are allocated the same highway capacity, motorists and the highway providers negotiate only over tolls. In contrast, motorists and the monopoly provider negotiate over tolls and the allocation of highway capacity, which enables motorists to determine the combination of tolls *and* capacity that maximizes consumer surplus. The difference between the negotiations is important because in the travelers' solution under duopoly, we find that motorists' welfare is *lower* than it is for the travelers' solution under monopoly. Travelers' welfare potentially improves when we allow the duopolists to have unequal capacity (column 4), but the gain still falls short of the gain negotiated with a monopolist because the monopolist can provide an

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[20] The findings under Stackelberg competition are very similar to those under Bertrand competition for all the scenarios and are available upon request.

untolled lane while a duopolist cannot because it will not break even.[21] Thus in a privatized highway market, motorists may be potentially better off negotiating with a monopoly than with a duopoly.

Public-private provision. Finally, the government may be willing to privatize only part of the highway and keep one route in the public sector. We assume the government privatizes the amount of capacity (part of or the entire second route) that maximizes consumer surplus and the improvement in its budget. Given the government's allocation of capacity, the public and private operators set prices—either simultaneously or sequentially with the public operator as the price leader—to maximize their own objectives (a graphical solution of the public-private duopoly equilibrium is shown in the appendix).

As indicated in table 6, the optimal capacity allocation for the government is to privatize only one lane (denoted route r1). Given this allocation, we find the equilibrium under Bertrand competition generates a welfare gain but a loss to motorists (we obtain a very similar result under Stackelberg competition).[22] When the government does not charge a toll on its route (5 lanes) and the private operator charges a high toll for express service on its lane, motorists who are willing to pay for significant improvements in travel time and reliability have the option to do so and, on average, motorists gain. But because a large part of the highway is unpriced, the gain in social welfare is less than the gain generated by the travelers' solution to negotiations with monopoly or duopoly operators. Motorists no longer realize a gain if the government does not

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[21] We obtain multiple equilibria for the travelers' solution with unequal capacity; although the one with the greatest differentiation in tolls yields the highest welfare gains to motorists. See the appendix for details.

[22] The welfare generated by the public operator, including consumer surplus and the budgetary improvement, exceeds the welfare generated by the public operator under alternative allocations of capacity.

rebate the gasoline tax, which would be justified because the government is still operating most of the highway.

Capacity Expansion. Our assessment of alternative competition scenarios for privatizing highways has reached the somewhat surprising conclusion that motorists may be better off if they can negotiate tolls and the allocation of capacity with a monopolist than with a duopolist or if a private firm competes with the government. In fact, this conclusion is strengthened if we account for operators' decisions on whether to add capacity.

Duopoly operators would not add a lane to the highway because it would give rise to unequal capacity among competitors and they both cannot gain from the additional lane if excess operating profits are constrained to zero as in the travelers' solution. (We could not find a unique equilibrium for the operators' solution under capacity expansion.) A monopoly would also not expand capacity if its excess profits were constrained to zero in negotiations, but if that constraint were relaxed then it would find it profitable to add a lane that would benefit motorists. Based on the parameters of our model and assuming the construction cost of an additional lane is \$2 million per mile, Figure 4 indicates that the potentially largest "win-win" bargaining outcomes occur when the additional lane is used to expand the number of (higher speed) lanes in route 2, meaning that route 1 would consist of 1 lane and route 2 would now consist of 6 lanes. Figure 5 then shows for this allocation of capacity that given an initial bargaining solution of either the travelers' solution, motorist's solution, or an intermediate solution, feasible "win-win" outcomes exist where an additional lane would increase marginal operating profits and consumer surplus.

Discussion

It is useful to assess our findings in light of certain assumptions and features of our model and sample. First, we assume that motorists' route and vehicle occupancy decisions are conditional on their choice of mode, residence and workplace location, and time of trip. Mode choice is not a particularly relevant consideration because of the small use of public transit in our sample of Orange County households. But by taking motorists' location and trip timing choices as exogenous, we may be understating the benefits of privatization because households could reduce the cost of higher tolls by moving closer to their workplace (assuming the reduction in transport costs exceeds the increase in housing costs) as well as by traveling at different times of day, or increase the benefits from faster and more reliable trip times by living further from their workplace in lower cost housing as well as by traveling at more convenient times of day.[23]

Our model accounts for motorists' heterogeneous preferences and we conclude that privatization is a potentially attractive policy if the private operator's pricing and capacity decisions is responsive to those preferences. In table 7, we show how our findings are affected when we ignore preference heterogeneity and assume that road users have homogeneous preferences. Generally, monopoly tolls are lower than they are for heterogeneous users because when users are heterogeneous, the monopolist sets high tolls to serve users with the highest value of time and reliability. With homogenous users, the travelers' bargaining solution results in a corner solution (i.e., the monopoly operator sets the lowest tolls that enable it to break even), and different market structures—monopoly, Bertrand duopoly, and Bertrand public-private competition—are less feasible politically because consumer surplus is always negative. In

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[23] Langer and Winston (2008) find that the social benefits of congestion pricing are much greater when households' residential location decisions are taken into account.

contrast, when users are heterogeneous, it is possible to obtain win-win outcomes for motorists and the highway provider(s).

As noted, our sample consists of Southern California motorists, who have a high value of time and reliability and who commute long distances, partly on a limited access highway. Thus, it would be incautious to suggest that our findings generalize to every metropolitan area in the United States. At the same time, major metropolitan areas, such as San Francisco, Seattle, New York, and Washington, DC, have travel conditions and motorists whose value of time and reliability are similar to those in Southern California—and there are several other cities with a notable share of drivers who are probably less than a decade away from willing to pay large sums to improve travel conditions.

Finally, following previous work on privatization, we have assumed that the government's sale price for the highway is aligned with market outcomes when the government's participation constraint is not binding; that is, the tolls under privatization without regulation are determined by market forces and the sale price is set to extract the private firm's excess operating profits under the tolls. Of course, the government may err in setting the sale price. If its price exceeds the price aligned with market outcomes, tolls would be inflated and the feasible range of win-win bargaining outcomes would be reduced. If the government's reservation sale price is lower than the value we have assumed based on construction costs, the feasible range of win-win bargaining outcomes would increase.

Conclusions

We have developed an equilibrium model of the government's decision to sell a highway and the supply and demand for highway services to investigate the economic effects of privatization. Because motorists' values of travel time and reliability vary widely, we find that privatization can raise motorists' and social welfare if it causes the highway operator(s) to allocate capacity and charge tolls that result in differentiated products that are aligned with motorists' varying preferences. This outcome can be achieved even if the highway is owned and operated by a monopolist, provided motorists are able to negotiate aggressively with the private highway operator to allocate capacity and determine tolls. In fact, motorists' may gain more from privatization if they negotiate with a monopoly highway provider than with duopoly providers or if the government owns part of the road and competes with the monopoly provider.

Armstrong and Sappington (2006), among others, point out that even if an industry is privatized, it may be appropriate to regulate it; thus, it could be argued that the government could represent consumers' interests by implementing regulations, which set consumer welfare maximizing tolls. But we have argued that government regulation is notoriously poor at facilitating an environment that is responsive to preference heterogeneity and we have found that the failure to create such an environment in the case of highways would significantly reduce the welfare gains from privatization. We have also argued that government does have an important role in setting the appropriate sales price; its failure to do so could adversely affect motorists.

We stress that our findings are conservative in the sense that we have focused on inefficiencies associated with current road pricing and capacity allocation, and to a certain extent, with current road maintenance policies. Privatization is also likely to reduce highway production costs, which are particularly important when the effects of truck traffic on pavement costs are considered, and to spur innovation in highway services, which would benefit all road users.[24]

Privatization is likely to be attractive in the current economic environment because all levels of government are interested in strategies—such as selling public assets like highways, transit systems, and office buildings—that could improve their budgets. To be sure, the United States has not had any recent experience with a fully privatized highway market; moreover, important uncertainties surround the conclusions reached here, especially whether negotiations would enable motorists to benefit from privatization, whether regulations may be desirable and effective, and whether government would set an appropriate sale price for the highway.

Recently, the federal government has begun to explore the issue of airport privatization by calling for privatization experiments. Accordingly, it would be useful for the government to carefully design some highway privatization experiments that go beyond the restrictive framework of public-private partnerships. We have identified some important features of a private highway market that should be borne in mind when experiments are designed and some uncertainties that experiments could help resolve. Hopefully, future work will provide additional motivation and guidance for policymakers who realize that the time has come to assess whether the private sector can improve on the public sector's provision of highway services.

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[24] As noted, the pavement damage caused by trucks is much greater than the damage caused by cars, and the gas taxes paid by trucks do not cover the pavement costs incurred by truck traffic (Small, Winston, and Evans (1989)). Thus, by not including trucks in the analysis, we are likely to understate the improvement in the government's budget from privatization.

Appendix

This appendix demonstrates the existence and uniqueness of the Wardrop equilibrium in our analysis and presents graphical solutions to private and public-private duopoly competition.

Wardrop Equilibrium

We show that a unique Wardrop equilibrium for the third stage of the overall game exists for a price vector $p \geq 0$. Define *allocation* $g : N \rightarrow \Omega$, which maps potential travelers to the choice set, to represent travelers' choices. Traveler $i's$ choice is denoted $g(i)$. The market share of alternative j under allocation g is denoted by S_j^g, and the corresponding traffic volume is $V_j^g \equiv \frac{N \cdot S_j^g}{O_j}$, where O_j is vehicle occupancy. The transportation network is a simple two-route network and traffic volumes on the two routes $(r1, r2)$ under allocation g are $V_{r1}^g = \sum_{j \in \Omega_{r1}} V_j^g$ and $V_{r2}^g = \sum_{j \in \Omega_{r2}} V_j^g$.

The utility of choosing not to travel in equation (1) of the text is not a function of traffic volume. Given a price, the utility function of a traveler choosing a travel alternative that is associated with a route in our choice set is a function of the traffic volume on the route because both travel time and travel time unreliability are increasing functions of the route's traffic volume. Formally, traveler $i's$ utility for choosing a travel alternative under allocation g can be expressed as

$$U_{ig(i)} = U_{ig(i)}\left(V_r^g\right) \text{ for } g(i) \neq 0, \qquad \text{(A.1)}$$

where the choice $g(i)$ is associated with route r and subscript i indicates that the utility function is individual specific. The utility function has two properties. The first is

$$U_{ig(i)}\left(V_r^{g}\right)<U_{ig(i)}\left(V_r^{g'}\right) \Leftrightarrow V_r^{g}>V_r^{g'}, \qquad \text{(A.2)}$$

which says that a traveler's utility of choosing a travel alternative decreases as the volume on the chosen route *i* increases. The second property is for $j,k \in \Omega_r$

$$U_{ik}\left(V_r^{g}\right)<U_{ij}\left(V_r^{g}\right)\Leftrightarrow U_{ik}\left(V_r^{g'}\right)<U_{ij}\left(V_r^{g'}\right). \qquad \text{(A.3)}$$

Since j and k are two travel alternatives on the same route, they must have different car occupancies. The property in (A.3) says that a traveler's preference for two alternatives on the same route, but with different car occupancies, is invariant to the traffic volume on the route.[25]

Allocation g is a Wardrop equilibrium if and only if under the allocation each traveler maximizes her utility given the traffic volumes and price; that is, $U_{ig(i)}=\max\left\{U_{i0},U_{i1},...,U_{iJ}\left|V_{r1}^{g},V_{r2}^{g},p\right.\right\}$ for all i. Konishi (2004) proves the uniqueness of the Wardrop equilibrium in transportation networks with heterogeneous commuters for a model with only route choice. We consider travelers' route and vehicle occupancy choices, but the proof of the uniqueness of the Wardrop equilibrium follows Konishi's idea.

We first show the existence of the Wardrop equilibrium. The third stage game of the paper is an example of the atomless game considered by Schmeidler (1973). The game is anonymous in the sense that travelers care only about the number of travelers for each alternative but do not care about who they are. Under anonymity, Schmeidler's result is that the Wardrop equilibrium exists.

The uniqueness of the Wardrop equilibrium depends on whether traffic volumes of the alternatives are the same for any equilibria g and g'. If the traffic volumes are the same, then the

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[25] For example, if a traveler prefers driving alone to using a carpool on a route when the route is not congested, the traveler still prefers driving alone to using a carpool on the route when the route is congested.

pricing decisions at the first stage and the welfare effects of the overall game are also the same for any Wardrop equilibria g and g'. To prove uniqueness, we first show that traffic volumes on the two routes are the same for any two equilibria; that is, if g and g' are two Wardrop equilibria, we have $V_{r1}^{g} = V_{r1}^{g'}$ and $V_{r2}^{g} = V_{r2}^{g'}$.

We prove this by contradiction. Suppose allocations g and g' are both Wardrop equilibria and traffic volumes on the two routes are different for g and g'. Without loss of generality, we can assume that $V_{r1}^{g} < V_{r1}^{g'}$. This implies that there exists a traveler i and an alternative $j \in \Omega_{r1}$ such that $g'(i) = j$ and $g(i) \neq j$. We can divide this possibility into the following cases:

Case 1: $g(i) = 0$. This case indicates that traveler i chooses alternative j under allocation g' but switches to the no-travel option under allocation g. We are able to construct the following inequalities, $U_{i0} \geq U_{ij}\left(V_{r1}^{g}\right)$, $U_{i0} \leq U_{ij}\left(V_{r1}^{g'}\right)$, and $U_{ij}\left(V_{r1}^{g'}\right) \geq U_{ij}\left(V_{r1}^{g}\right)$; from property (A.2), the last inequality means that $V_{r1}^{g} \geq V_{r1}^{g'}$. Thus, we obtain a contradiction.

Case 2: $g(i) \in \Omega_{r1}$. This case indicates that traveler i stays on the same route but switches to another alternative with larger vehicle occupancy. This case contradicts property (A.3) because it implies that $U_{ig(i)}\left(V_{r1}^{g}\right) \geq U_{ij}\left(V_{r1}^{g}\right)$ and $U_{ij}\left(V_{r1}^{g'}\right) \geq U_{ig(i)}\left(V_{r1}^{g'}\right)$.

Case 3: $g(i) \in \Omega_{r2}$. This case indicates that traveler i chooses alternative j under allocation g' but switches to an alternative that is associated with route *r2* under allocation g. By (A.2), we have $U_{ij}\left(V_{r1}^{g}\right) > U_{ij}\left(V_{r1}^{g'}\right)$. Since g and g' are both equilibrium allocations, we can have the other two inequalities, $U_{ig(i)}\left(V_{r2}^{g}\right) \geq U_{ij}\left(V_{r1}^{g}\right)$ and $U_{ij}\left(V_{r1}^{g'}\right) \geq U_{ig(i)}\left(V_{r2}^{g'}\right)$. Combining the three inequalities, we have $U_{ig(i)}\left(V_{r2}^{g}\right) > U_{ig(i)}\left(V_{r2}^{g'}\right)$ which implies $V_{r2}^{g} < V_{r2}^{g'}$. Given the total number of travelers on the routes is fixed (from case 1), both routes can be less congested under the allocation g only when some travelers on the routes switch to alternatives with larger vehicle occupancy. Case 2 indicates that it is impossible for travelers to make such changes on the same route, so we can conclude that: (a) there exists one traveler (denoted by n) who switches from an alternative on route $r1$ to an alternative (denoted by m_2) with larger vehicle occupancy on route $r2$; (b) there exists one traveler (denoted by h) who switches from an alternative on route $r2$ to an alternative (denoted by k_1) with larger vehicle occupancy on route $r1$. From (a) we have $U_{nm_2}\left(V_{r2}^{g}\right) > U_{nm_1}\left(V_{r1}^{g}\right)$ with m_1 denoting the alternative on route $r1$ with the same vehicle occupancy as m_2; from (b) we have $U_{hk1}\left(V_{r1}^{g}\right) > U_{hk_2}\left(V_{r2}^{g}\right)$ with k_2 denoting the alternative on route $r2$ with the same vehicle occupancy as k_1. The first inequality requires $V_{r1}^{g} > V_{r2}^{g}$ and the second inequality requires $V_{r1}^{g} < V_{r2}^{g}$, which again results in a contradiction.

Summarizing the three cases, we can conclude that if g and g' are two equilibrium allocations, $V_{r1}^{g} = V_{r1}^{g'}$ and $V_{r2}^{g} = V_{r2}^{g'}$. But although traffic volumes are the same, the composition of vehicles with different occupancies can be different for g and g'. If this is true, pricing decisions at the second stage and the welfare effects of the overall game can be different for the two equilibria.[26] It is also the case that we can find an alternative j such that $V_{j}^{g} \neq V_{j}^{g'}$; that is,

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[26] For example, operators charge different prices for carpoolers and solo drivers under a policy of high-occupancy-tolls (HOT).

there exists one traveler with different choices for these two equilibria. However, since $V_{r1}^{g} = V_{r1}^{g'}$ and $V_{r2}^{g} = V_{r2}^{g'}$, a traveler obtains the same utility under the two equilibria from choosing an alternative; accordingly, her ranking of the alternatives should be the same for g and g'. Thus, given prices, we obtain a unique Wardrop equilibrium.

Solutions to Duopoly Equilibrium

We present graphical solutions to private and public-private Bertrand duopoly competition. Figure A1 pertains to private duopoly competition without bargaining between operators and travelers. Two equilibria exist; one can be obtained by switching the tolls of the other. Tolls are strategic substitutes when a rival's toll is low and strategic complements when a rival's toll is high. The main explanation for the V-shape toll reaction functions is motorists' preference heterogeneity. Users with low VOT and VOR take the route with the lower toll. So, if the toll on route r2 is low, operator r1 prefers to cater to high VOT users (analogous to the long side of the market in a Hotelling line model) and sets a high value for the toll on route r1. As the toll on route r2 rises, the mix of travelers on route r1 shifts toward a lower VOT and operator 1 finds it profitable to cut the toll on route r1 even though usage increases. This explains why the reaction function of operator r1 is downward-sloping for low values of the toll on route r2.

At some point, the toll on route r2 is close to \$10 according to the figure; operator r1 finds it profitable to switch from a high-toll high-quality strategy to a lower toll and lower quality. The figure shows that the reaction function takes a small downward jump. As the toll on route r2 rises further, the mix of travelers on route r1 shifts toward a higher VOT and operator 1 responds by raising the toll on route r1; the response function of operator r1 is therefore upward-sloping for higher values of the toll on route 2.

Figure A2 presents duopoly bargaining equilibria for the travelers' solution given that the optimal sale price of the highway is the government's reservation price (the highway's construction cost). Again, two equilibria exist as one can be obtained by switching the tolls of the other and one of the two operators breaks even. Tolls are strategic complements when a rival's toll is low and they are strategic substitutes when a rival's toll exceeds a threshold. When a rival's toll is very low, an operator can improve consumer surplus by increasing its toll to maintain toll differences that benefit high VOT users. When a rival's toll exceeds a certain level, about $2.70 according to Figure A2, the operator cuts its toll to the break-even level to benefit low VOT users. Because of the break-even requirement, tolls are quite unresponsive to a rival's toll when they are strategic substitutes. At the break-even level, a higher sale price of the highway would shift up operator r1's response curve and shift operator r2's response curve to the right such that tolls under the equilibria would be higher and reduce consumer surplus.

Figure A3 presents duopoly bargaining equilibria under the operators' solution. The key difference between this competitive environment and duopoly competition without bargaining is that tolls are also strategic substitutes when a rival's toll is high; thus, an operator's response curve overlaps with its rival's response curve leading to multiple equilibria. Tolls are strategic substitutes when a rival's toll is high because in response to an increase in the rival's toll, an operator has to reduce its own toll to satisfy the requirement that the change in consumer surplus will be nonnegative. Tolls cannot be too low given the assumption that the purchase price of the highway cannot be lower than the government's reservation price (construction cost).

Figures A4 and A5 present the travelers' solution and the operators' solution under Bertrand competition with unequal capacity allocation. Changing the capacity allocation does not alter the basic findings from duopoly bargaining with equal capacity. However, the two equilibria for the travelers' solution presented in Figure A4 have different welfare effects; the one with the higher toll on route r1 (the route with smaller capacity) generates a larger increase in consumer surplus. The government's optimal sale price is at the lowest possible level, the reservation price; a higher sale price would lead to higher tolls under the equilibria and eventually reduce consumer surplus.

Finally, figure A6 presents duopoly equilibria under public-private competition. There are two equilibria for Bertrand public-private competition but the two equilibria have different welfare effects; equilibrium A dominates equilibrium B in terms of both consumer surplus change and social welfare. The profits to the private operator under equilibrium A are also higher than the profits under equilibrium B. Under the SPE, the government can restrict the equilibrium of the Bertarnd public-private competition to the better outcome by setting the sale price of the highway as the present value of private firm's excess operating profits under equilibrium A.

The reaction function for the private operator in Figure A6 is qualitatively similar to the reaction functions in Figure A1 except for a much bigger discontinuity at the transition point. In contrast, the public operator's reaction curve is nearly flat. This may be because the public operator takes into account not only the VOT for the marginal user but also the VOT for the inframarginal users. The public operator is therefore reluctant to cut the toll because this would exacerbate congestion for users with the highest VOT.

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Table 1. Estimated Coefficients for the Route-Vehicle Occupancy Choice Model

Variable	Coefficient[a]
Toll ($)	-1.4580
Toll × dummy for high household annual income (> $60K)	0.8411
Median travel time (minutes) × trip distance (units of 10 miles)	-0.3489
Median travel time × trip distance squared	0.0684
Median travel time × trip distance cubed	-0.0030
Travel-time uncertainty (80th percentile minus the median) (minutes)	-0.4541
HOV2 dummy	-6.9854
HOV3 dummy	-12.580
Female × age 30−50 × household size × carpool dummy[b]	0.8735
Random components of coefficients	
Standard deviation of travel-time coefficient	0.3866
Standard deviation of travel-time uncertainty coefficient	0.6009
Common standard deviation of HOV2 and HOV3 dummies	6.2597

Source: Small, Winston, and Yan (2006).

[a] All coefficients are statistically significant at the five percent level.

[b] The carpool dummy is set to one if the route-vehicle occupancy choice includes HOV2 or HOV3.

Table 2. Value and Heterogeneity of Travel Time and Reliability [a]

Item	Median estimate
Value of Median Travel Time	
Dollars per hour	19.63
As a percent of the wage [b]	85
Value of Reliability	
Dollars per hour	20.76
As a percent of the wage [b]	90
Heterogeneity [c]	
Median travel time	19.02
Reliability	35.51

[a] Source: Small, Winston, and Yan (2006).

[b] The wage rate, estimated in Small, Winston, and Yan (2005), is about $23 per hour.

[c] Heterogeneity is expressed here as the interquartile range of the quantity in question across individuals.

Table 3. Welfare effects under government regulation (with the gas tax rebate)[a]

	Base case: current situation	Government maximizes the sum of consumer surplus and operating profits	Government maximizes only consumer surplus
Capacity (vehicles/hour)	12000	12000	12000
Sale price ($ million/mile)	N.A.	49.4	12.0
Toll ($)	0.00	9.31	1.69
Travel times (min.)	20.00	12.33	19.12
Aggregated choice shares (%):			
No travel on the corridor	8	7	6
Travel on the corridor	92	93	94
For those who travel on the corridor			
Solo driving	80	37	74
HOV2	17	43	21
HOV3	3	20	5
Operating profits: one period ($/person) [b, c]	0.00	3.66	0.89
Operating profits: present value ($ million/mile)[d]	0.00	49.4	12.0
Change in gov't budget: one period ($/person)[c, e]	0.00	3.44	0.67
Change in consumer surplus: one period ($/person)[c]	0.00	-1.87	0.52
Change in social welfare: one period ($/person)[c, f]	0.00	1.57	1.19

[a] We assume that the government does not offer differentiated tolls on the two routes.

[b] Operating profits are determined as 65% of the toll revenues (Poole and Samuel (2008)).

[c] The change in consumer surplus, government budget, and social welfare is measured relative to the no-toll scenario. These items and operating profits are divided by the total number of potential users *N*.

[d] We assume a 4.5% discount rate.

[e] The change in the government's budget is calculated by subtracting the government's gas tax revenues and maintenance expenditures under the no-toll scenario from the highway sale revenue under privatization. Gas tax revenues are calculated assuming average gas mileage of 16 miles per gallon and a gasoline tax rate of $0.49 per gallon.

[f] The welfare change is the sum of the change in the government budget and consumer surplus because the government's sale price extracts excess operating profits.

Table 4. Welfare Effects under Monopoly Provision (with the gas tax rebate)

	Base case: current situation	Monopoly	Monopoly bargaining: travelers' solution	Monopoly bargaining: operator's solution	Base case: with traffic growth [d]	Monopoly with traffic growth [d]	Monopoly bargaining with traffic growth: travelers' solution [d]	Monopoly bargaining with traffic growth: operator's solution [d]
Capacity (vehicles/hour) [a]								
Route r1	6000	6000	2000	2000	6000	6000	2000	2000
Route r2	6000	6000	10000	10000	6000	6000	10000	10000
Sale price ($ million/mile)	N. A.	63.6	12.0	42.8	N. A.	75.8	43.0	53.9
Toll ($)								
Route r1	0.00	22.14	0.00	1.59	0.00	22.77	0.00	1.74
Route r2	0.00	22.14	2.19	10.55	0.00	22.77	8.77	12.95
Travel times (min.):								
Route r1	20.00	9.50	34.43	50.10	24.40	9.69	66.76	67.53
Route r2	20.00	9.50	17.62	10.97	24.40	9.69	13.76	11.13
Aggregated choice shares (%):								
No travel on the corridor	8	31	5	7	16	32	10	12
Travel on the corridor	92	69	95	93	84	68	90	88
For those who travel on the corridor								
Solo driving	80	8	74	41	80	8	47	33
HOV2	17	50	21	40	17	50	38	44
HOV3	3	42	5	19	3	42	15	23
Operating profits: one period ($/person) [b,c]	0.00	4.71	0.89	3.17	0.00	4.67	2.67	3.33
Operating profits: present value ($ million/mile)[e]	0.00	63.6	12.0	42.8	0.00	75.8	43.0	53.9
Change in government budget: one period ($/person) [c,f]	0.00	4.59	0.67	2.95	0.00	4.44	2.44	3.10
Change in consumer surplus: one period ($/person)[c]	0.00	-6.33	1.40	0.00	0.00	-4.91	1.56	0.00
Change in welfare: one period ($/person)[c, g]	0.00	-1.84	2.07	2.95	0.00	-0.47	4.00	3.10

[a] Capacity is allocated optimally for each scenario.

[b] Operating profits are determined as 65% of the toll revenues.

[c] The change in consumer surplus, government budget, and social welfare change are measured relative to the no-toll scenario. These items and operating profits are divided by the total number of potential users *N*.

[d] Population size (*N*) is increased 20% in the scenarios with traffic growth.

[e] We assume a 4.5% discount rate.

[f] The change in the government's budget is calculated by subtracting the government's gas tax revenues and maintenance expenditures under the no-toll scenario from the highway sale revenue under privatization. Gas tax revenues are calculated assuming average gas mileage of 16 miles per gallon and a gasoline tax rate of $0.49 per gallon.

[g] The welfare change is the sum of the change in the government budget and consumer surplus because the government's sale price extracts excess operating profits.

Table 5. Welfare Effects under Duopoly Provision (with the gas tax rebate)

	Base case: current situation	Bertrand competition without bargaining [f]	Bertrand competition with bargaining: travelers' solution [f]	Bertrand competition with bargaining: travelers' solution (two equilibria)	
Capacity (vehicles/hour) [a]					
Route r1	6000	6000	6000	4000	
Route r2	6000	6000	6000	8000	
Sale Price ($ million/mile)					
Route r1	N. A.	25.5	6.0	4.0	
Route r2	N. A.	25.5	6.0	8.0	
Toll ($)					
Route r1	0.00	10.25	6.11	7.55	1.58
Route r2	0.00	9.84	1.58	1.63	4.22
Travel times (min.):					
Route r1	20.00	11.61	13.86	12.74	23.79
Route r2	20.00	12.26	22.17	20.61	15.84
Aggregated choice shares (%):					
No travel on the corridor	8	8	5	5	5
Travel on the corridor	92	92	95	95	95
For those who travel on the corridor					
Solo driving	80	33	64	64	67
HOV2	17	45	27	27	26
HOV3	3	22	9	9	7
Operating profit: one period ($/person) [b]					
Route r1	0.00	1.89	1.32	1.02	0.30
Route r2	0.00	1.92	0.45	0.59	1.34
Operating profits: present value ($ million/mile)[c]					
Operator r1	0.00	25.5	18.0	13.8	4.0
Operator r2	0.00	25.9	6.0	8.0	18.1
Change in government budget: one period ($/person) [b, d]	0.00	1.67	0.23	0.37	0.08
Change in consumer surplus: one period ($/person) [b]	0.00	-2.14	0.65	0.92	0.51
Change in social welfare: one period ($/person) [b, e]	0.00	1.45	2.20	2.31	1.93

[a] The routes have equal capacity under duopoly provision. We also show results with unequal capacity allocation for Bertrand duopoly with bargaining. There are multiple equilibria for the operators' solution under Bertrand duopoly with bargaining. Details are shown in the appendix.

[b] The change in consumer surplus, government budget, and social welfare are measured relative to the no-toll scenario. These items and operating profits are divided by the total number of potential users *N*.

[c] We assume a 4.5% discount rate.

[d] The change in the government budget is calculated by subtracting the government's gas tax revenues and maintenance expenditures under the no-toll scenario from the highway sale revenue under privatization. Gas tax revenues are calculated assuming average gas mileage of 16 miles per gallon and a gasoline tax rate of $0.49 per gallon.

[e] In equilibrium, the government's sale price extracts the excess operating profits of the operator earning the lowest profits (because the government cannot charge different sale prices for the highway capacity). The change in welfare is the sum of the change in the government budget and consumer surplus and the excess operating profits of the operator earning the highest operating profits.

[f] Another equilibrium is obtained by switching the tolls on the two routes.

Table 6. Welfare Effects under Public-Private Provision (with gas tax rebate)

	Base case: current situation	Bertrand Competition	Free Public Route	Free Public Route without the gas tax rebate
Capacity (vehicles/hour) [a]				
Route r1 (private)	6000	2000	2000	2000
Route r2 (public)	6000	10000	10000	10000
Sale price ($ million/mile)	N. A.	10.3	11.2	10.4
Toll ($)				
Route r1	0.00	8.80	16.57	15.27
Route r2	0.00	10.22	0.00	0.00
Travel times (min.):				
Route r1	20.00	18.74	10.30	10.32
Route r2	20.00	11.28	22.42	21.67
Aggregated choice shares (%):				
No travel on the corridor	8	7	7	8
Travel on the corridor	92	93	93	92
For those who travel on the corridor				
Solo driving	80	34	74	74
HOV2	17	44	20	20
HOV3	3	22	6	6
Operating profits: one period ($/person) [b, c]				
Route r1	0.00	0.76	0.83	0.77
Route r2	0.00	2.65	0.00	0.00
Private operator’s operating profits: present value ($ million/mile)[d]	0.00	10.3	11.2	10.4
Government budget change: one period ($/person) [b, e]	0.00	3.19	0.61	0.55
Consumer surplus change: one period ($/person)[b]	0.00	-1.72	1.01	-0.21
Social welfare change: one period ($/person)[b, f]	0.00	1.47	1.62	0.34

[a] Capacity allocation between the two routes is determined by the government to maximize consumer surplus and its toll revenue.

[b] The change in consumer surplus, government budget, and social welfare are measured relative to the no-toll scenario. These items and operating profits are divided by the total number of potential users *N*.

[c] Based on Poole and Samuel (2008), operating profits are 57% of the toll revenues for the public operator (operator r2) and 65% of the toll revenues for the private operator (operator r1).

[d] We assume a 4.5% discount rate.

[e] The change in the government budget is calculated by subtracting the government’s gas tax revenues and maintenance expenditures under the no-toll scenario from the highway sale revenues and public operator’s operating profits. Gas tax revenues are calculated assuming average gas mileage of 16 miles per gallon and gasoline tax rate of $0.49 per gallon.

[f] The change in social welfare is measured as the sum of the change in the government budget and consumer surplus because the government's sale price extracts excess operating profits.

Table 7. Simulation Results with Homogeneous Road Users (with the gas tax rebate)[a]

	Base: current situation	Monopoly	Monopoly bargaining: travelers' solution	Bertrand Duopoly Competition	Free Public Route without the gas tax rebate
Capacity (vehicles/hour)					
Route r1	6000	6000	6000	6000	2000
Route r2	6000	6000	6000	6000	10000
Sale price ($ million/mile)					
Route r1	N. A.	13.8	6.0	13.6	2.4
Route r2	N. A.	13.8	6.0	13.6	N. A.
Toll ($)					
Route r1	0.00	5.71	1.73	5.51	4.56
Route r2	0.00	5.71	1.73	5.51	0.00
Travel times (min.):					
Route r1	20.00	11.39	18.19	11.68	11.38
Route r2	20.00	11.39	18.19	11.68	20.65
Aggregated choice shares (%):					
No travel on the corridor	28	52	31	50	32
Travel on the corridor	72	48	69	50	68
For those who travel on the corridor					
Solo driving	100	100	100	100	100
HOV2	0	0	0	0	0
HOV3	0	0	0	0	0
Operating profits: one period ($/person)					
Route r1	0.00	0.89	0.38	0.88	0.24
Route r2	0.00	0.89	0.38	0.88	0.00
Change in government budget: one period ($/person)	0.00	1.56	0.54	1.54	0.02
Change in consumer surplus: one period ($/person)	0.00	-0.48	-0.09	-0.45	-0.10
Operating profits: present value ($ million/mile)					
Route r1	0.00	13.8	6.0	13.6	2.4
Route r2	0.00	13.8	6.0	13,6	0.00
Change in social welfare: one period ($/person)	0.00	1.08	0.45	1.09	-0.08

[a] We modify the demand model in Table 1 in the following ways to eliminate the heterogeneity in motorists' preferences: 1. set the random components of the coefficients to zero; 2. evaluate the toll, time, and carpool dummy coefficients at the means of the motorists' profiles. We recalibrate the parameters $\left(N,\lambda,\bar{\delta},\hat{\delta}\right)$ after those modifications following the same procedures described in the text.

Figure 1. Trade-off between monopoly operating profits and the change in consumer surplus under bargaining solutions for different allocations of capacity.

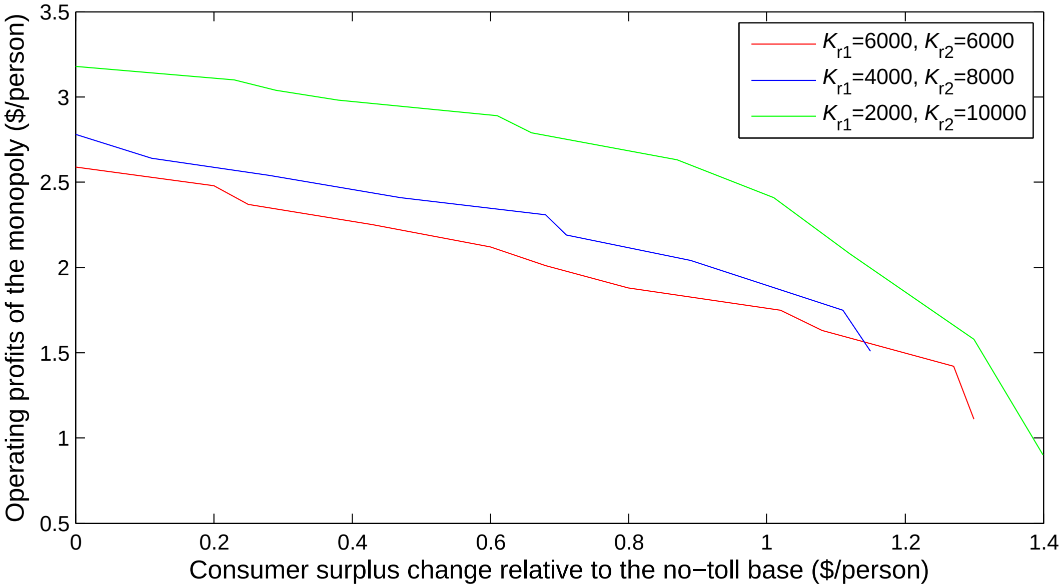

Figure 2. Optimal tolls and consumer surplus under bargaining solutions

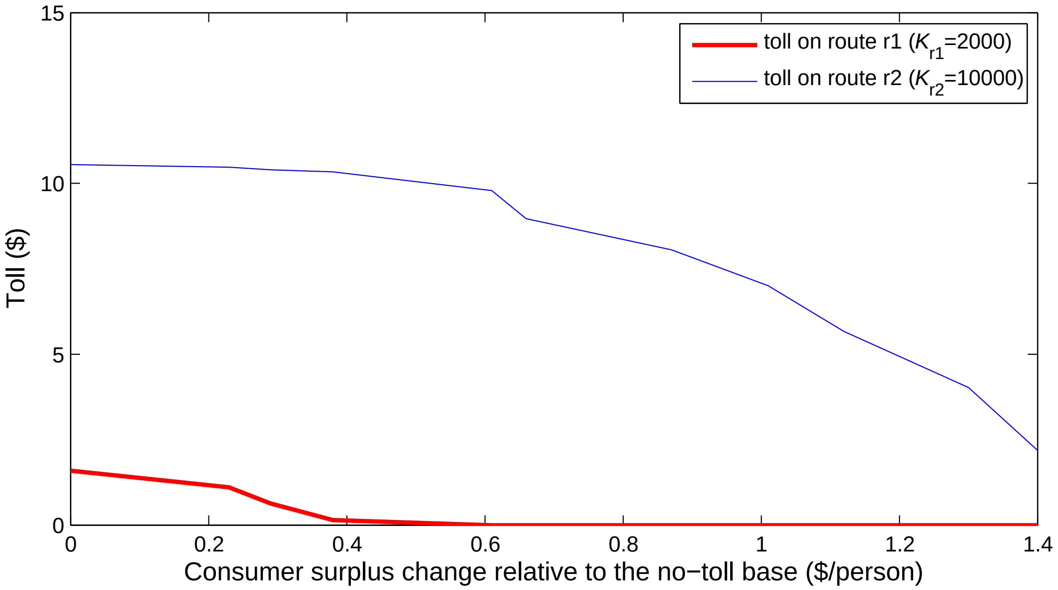

Figure 3. Government's optimal sale price and consumer surplus under bargaining solutions

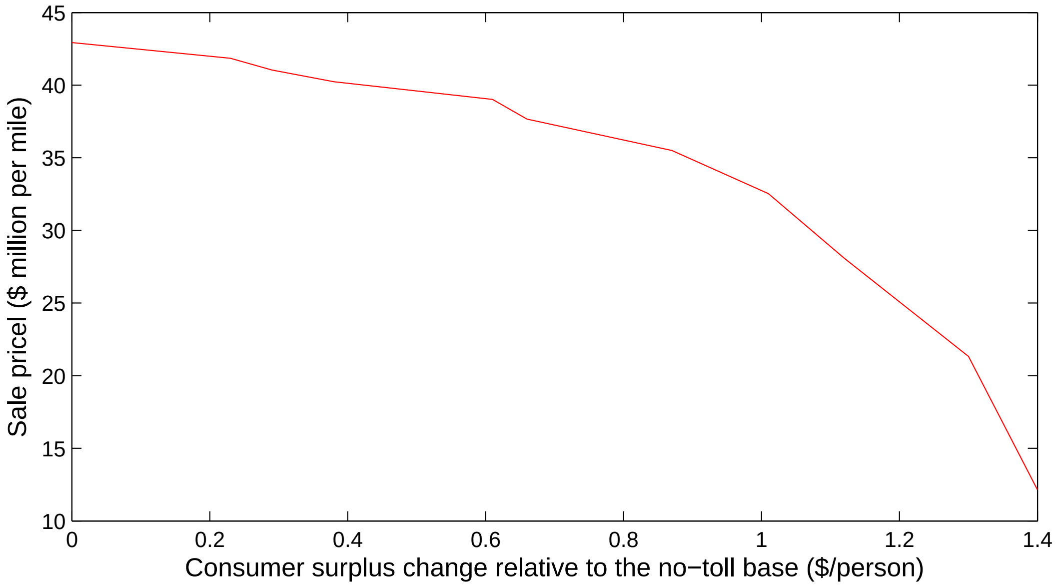

Figure 4. Trade-off between monopoly operating profits and the change in consumer surplus under bargaining solutions after adding one more lane for different allocations of capacity

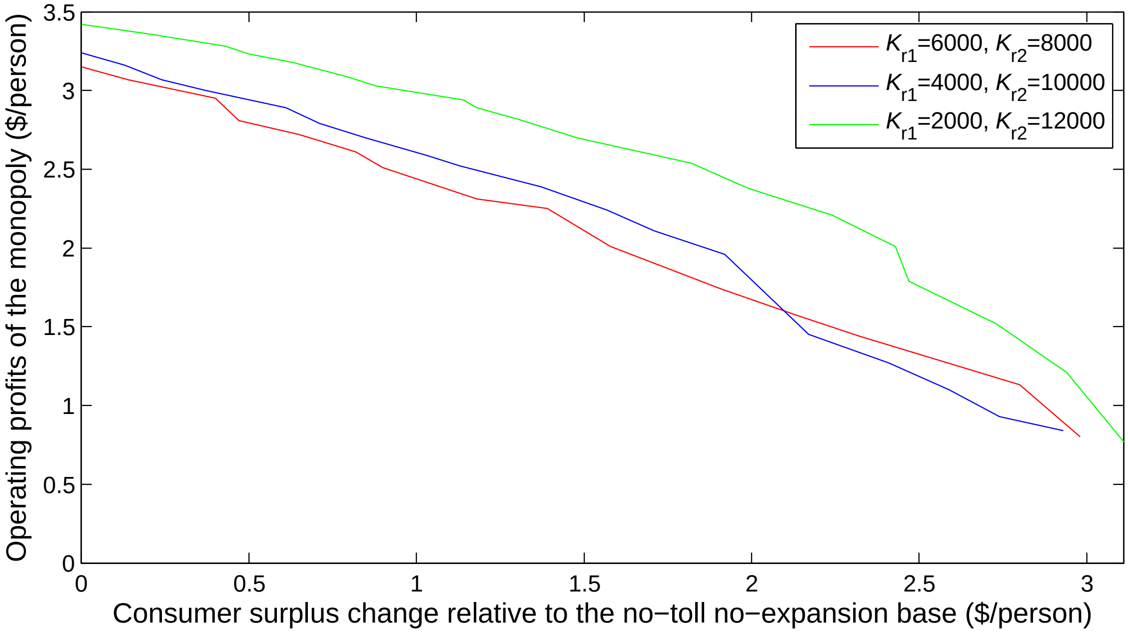

Figure 5. Feasible win-win outcomes for travelers and the operator from expanding capacity

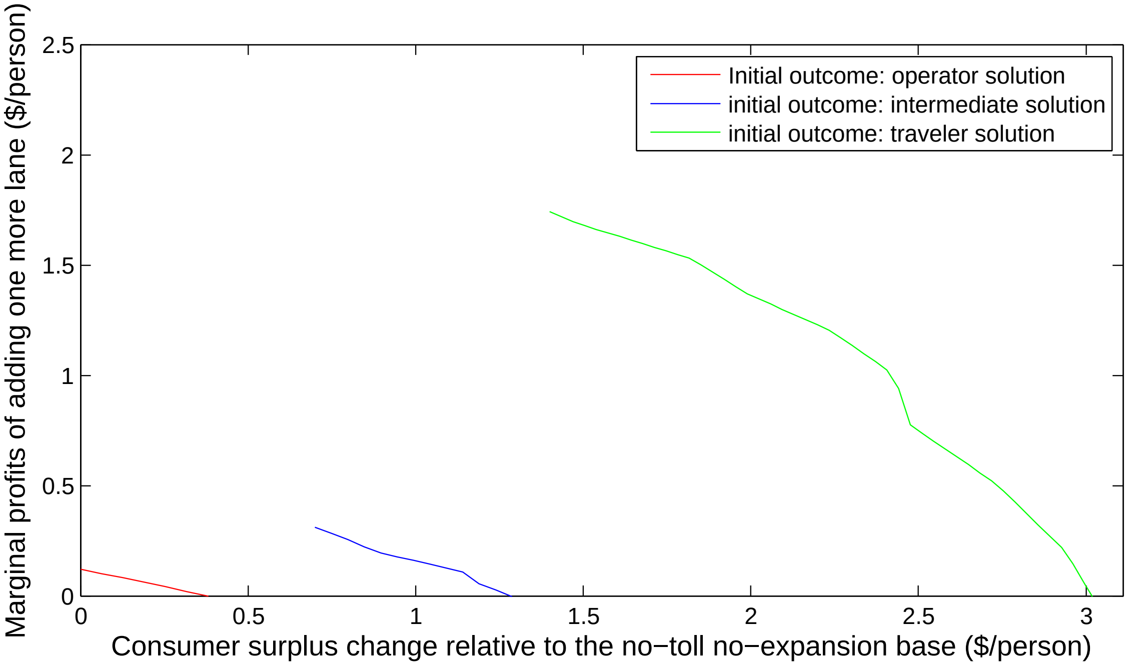

Figure A1. Solutions to Private Duopoly Competition

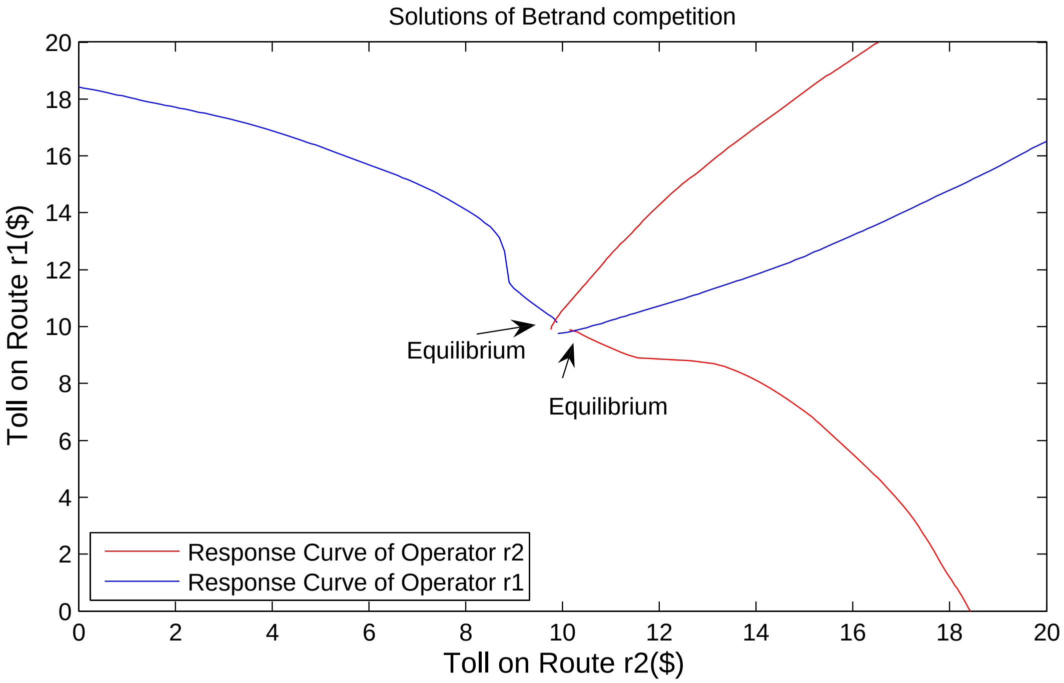

Figure A2. Solutions to Private Duopoly Competition with Bargaining: Travelers' Solution

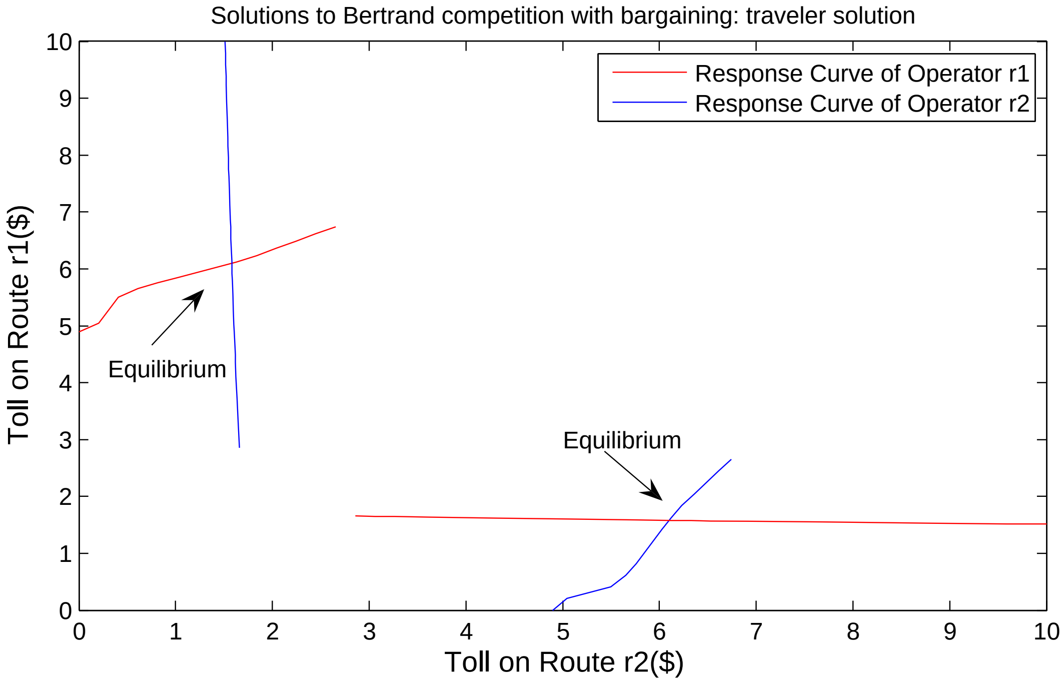

Figure A3. Multiple Equilibria under Duopoly Competition with Bargaining: Operator's Solution

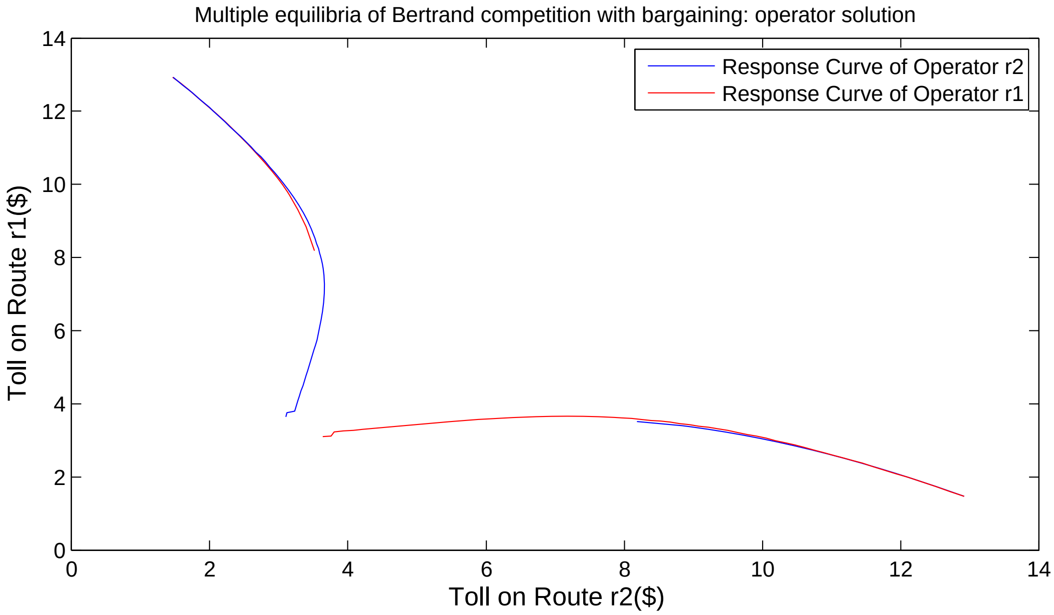

Figure A4. Solution to Duopoly Competition with Bargaining and Unequal Capacity: Travelers' Solution

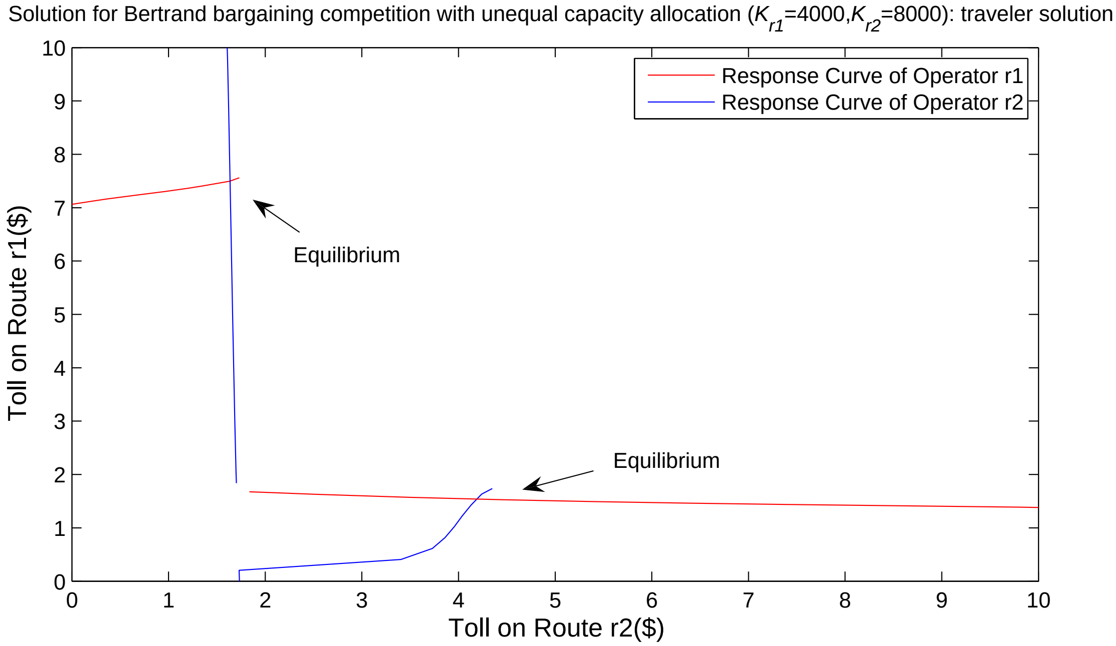

Figure A5. Multiple Equilibria under Duopoly Competition with Bargaining and Unequal Capacity: Operators' Solution

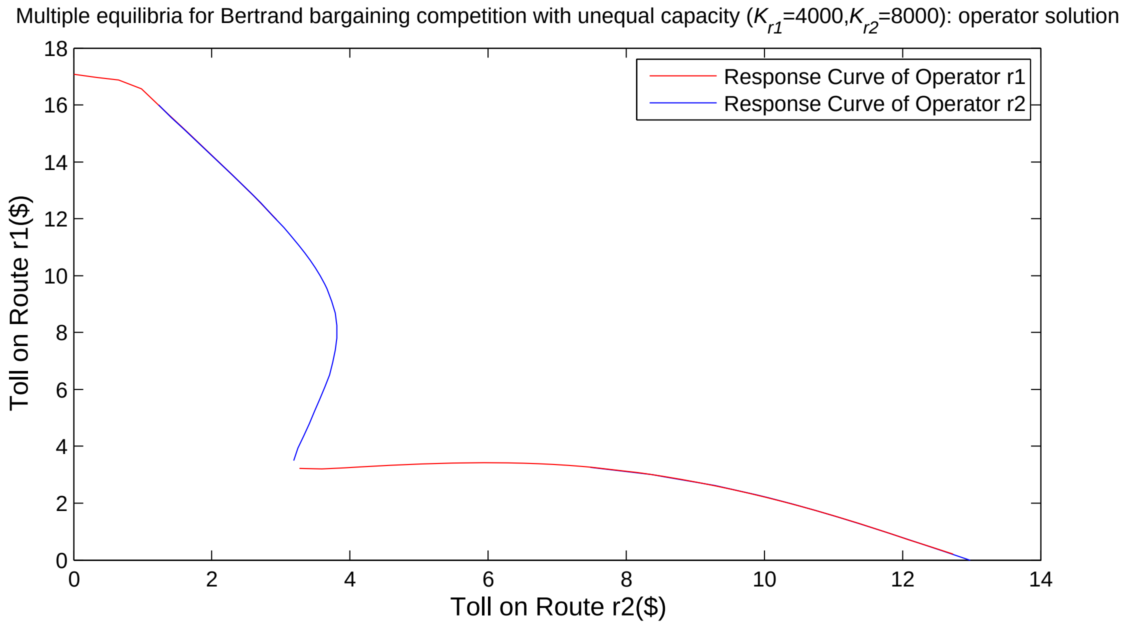

Figure A6. Solutions to Public-Private Duopoly Competition