Journal of Public Economics 95 (2011) 993–1005

Contents lists available at ScienceDirect

Journal of Public Economics

journal homepage: www.elsevier.com/locate/jpube

Can privatization of U.S. highways improve motorists' welfare?

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ARTICLE INFO

Article history:
Received 18 August 2010
Received in revised form 6 January 2011
Accepted 18 January 2011
Available online 2 February 2011

Keywords:
Highway privatization
Preference heterogeneity
Mixed logit

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, and motorists' heterogeneous preferences for speedy and reliable travel. We find motorists are able to benefit from privatization by negotiating tolls with private providers that increase their consumer surplus. Surprisingly, we find that by obtaining tolls and service that align with their varying preferences, motorists may be better off negotiating with a monopolist than with duopoly providers or under public–private competition. Toll regulation may be counterproductive because it is likely to treat motorists as homogeneous.

America's $2.5 trillion road system is experiencing a "perfect storm:" traffic congestion is imposing greater costs on motorists and shippers; poorly maintained highways 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.

Policymakers have sought the private sector's assistance to improve highway finance by forming so-called public–private partnerships (PPPs), where the government leases a road to a private investor(s) for a specified period and the investor(s) earns an acceptable rate of return.[1] But if the contract between the private firm and the government is poorly structured and prevents efficient pricing, highway travel conditions may not improve (Engel et al., 2007). A pure market solution–highway privatization–may be an attractive alternative, but travelers may be harmed if the private operator is able to exploit market power and set excessive tolls (Vickers and Yarrow, 1991).

Because economic theory cannot resolve whether highway privatization could improve economic welfare–especially for motorists–we present exploratory empirical evidence to shed light on the issue. Privatization is becoming a viable policy option 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. In addition, the private sector could help maintain and rehabilitate the road network at a time when public sector budgets are being severely strained.

We develop a stylized model where responsibility for providing highway services is transferred from the public sector to a private firm or firms, and we analyze it empirically using data from long-distance commuters on a major highway in California. Although privatization is generally 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 do not claim that our model characterizes how highway privatization would actually evolve in practice; an accurate prediction is especially difficult because of the heterogeneous preferences of travelers and other stakeholders. Accordingly, we explore a range of plausible privatization and regulatory outcomes including provision by a private monopoly, duopoly, and separate public and private operators. We find that motorists could benefit from tolls on private highways if they are able to negotiate differentiated tolls with a private operator(s) that broadly reflect their heterogeneous preferences for speed and reliability. The characterization of negotiated or contract equilibrium is well-established in transportation markets such as intercity freight rail service (Meyer and Tye, 1988). Our result does not appear to be extreme because a wide range of negotiated equilibria exist where privatization benefits motorists and the private operator(s). Surprisingly, we find that motorists are likely to achieve a larger welfare gain negotiating with a monopoly operator than with duopoly operators or if the monopoly competes against a public operator because unlike private or public–private duopolists a monopolist can allocate highway capacity to provide different levels of service, which enables motorists to negotiate over tolls *and* capacities.

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[1] Examples of PPPs include the Chicago Skyway, Indiana toll road, and the proposed Trans-Texas Corridor; high-occupancy-toll (HOT) lanes, where motorists pay a toll to travel on a high-occupancy-vehicle (HOV) lane, in California and Texas and that are under construction in the Washington, D.C. metropolitan area; and the Dulles–Greenway private toll road.

0047-2727/$ – see front matter
doi:10.1016/j.jpubeco.2011.01.005

In the possible interest of fairness and administrative simplicity, the government may choose to impose a uniform toll that we find generates only modest service time benefits to travelers with high values of time and reliability and harms travelers with lower values of time. Thus, we argue the government should not regulate private operators' tolls if, as is often the case, it treats consumers as homogeneous and discourages product differentiation.

1. Background literature

Previous literature suggests that highway privatization may lead to some form of congestion pricing, but that its efficiency and distributional effects are likely to depend on competitive alternatives to the private road, travelers' preference heterogeneity, and how the government allocates gas tax revenues. Knight (1924) injected a constructive role for privatization by arguing that a private road would set an optimal congestion toll if a perfect substitute provided by an alternative free uncongested (public) road or by an alternative mode were available to travelers. 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. 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.

Turning to highway operations, circumstantial evidence exists in the United States that production efficiency would improve if a private road operator replaced a public authority. For example, Roth (2005) reports that state highway officials estimate that federal regulations raise highway project costs 20–30%.

2. Model

We develop a model to characterize plausible highway privatization scenarios and to estimate privatization's welfare effects, with particular interest in identifying conditions, if any, under which motorists and society would gain from the policy. We make certain assumptions to simplify our analysis and, in the final section, assess the implications of the most important ones for our findings. Detailed discussions of some of the methodological procedures and additional findings are contained in our supplement on this journal's website.

We consider a multiple-lane highway that 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. Assuming a state decides to sell the carpool lanes to a private operator,[2] privatization 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 public highway authority to operate the general purpose lanes as a free road or a toll road (public–private competition). Regulatory options include having the government regulate tolls and, as an alternative, learning from certain travelers' and shippers' behavior in the aftermath of intercity transportation deregulation and allowing motorists to organize into a bargaining unit to improve their bargaining power and having a third-party negotiate tolls on their behalf. Third-party logistics firms have represented freight shippers in contract negotiations with railroads and motor carriers to obtain lower rates while governments and travel departments of large organizations have negotiated with airlines to obtain lower fares for their employees (Winston, 1998). The American Automobile Association has represented motorists' interests in many issues and it, or another entity, could represent motorists in toll negotiations. Free riding could be prevented if electronic tolling were used to charge all motorists for using the highway.

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 regulatory policy. A private highway owner(s) is assumed to set profit maximizing tolls or tolls that are determined in negotiations with a third-party representing motorists. 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.

We recognize that it is possible to configure the toll roads so that they form a complicated network instead of two sets of parallel traffic lanes. We discuss how alternative road configurations may affect our findings in the concluding section of the paper.

Turning to road users, we capture their heterogeneous preferences for highway services by using a demand model that accounts for the variability in their 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, highway travel and production costs, government and private firm behaviors, and equilibrium.

2.1. Demand

Let $\Omega = \{0,1,\ldots,J\}$ 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:

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

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:

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

[2] As an example, California could decide to privatize the carpool lanes of a highway if those lanes do not meet minimum federal standards requiring average peak-period speeds of 45 miles per hour. By introducing road pricing, the private operator could increase highway speeds.

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 Eq. (2) are normally distributed, conditional on an individual's observed profile denoted by Z_i; hence,

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

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.

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:

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

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

Based on this specification of demand, the change in motorists' consumer surplus attributable to the introduction of highway tolls is defined by the log-sum rule for nested logit (Choi and Moon 1997),

$$CS(p) = \sum_i \int_{\Theta_i} \frac{1}{\tau_i} \Delta \left\{ \ln \left[e^{\delta_0} + e^{\lambda D_i} \right] \right\} \cdot f(\Theta_i | Z_i) d\Theta_i, \tag{8}$$

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

2.2. Demand model parameters

The values of the parameters of the route–vehicle occupancy choice model (Eq. (2)) are obtained from Small et al. (2006), hereafter SWY. SWY assessed the efficiency of high-occupancy-vehicle (HOV) and high-occupancy-toll (HOT) lanes. They conducted surveys in 1999 and 2000–a stable period of highway travel–to measure 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% 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).

General assumption 1. The three choices are assumed conditional on mode choice (car versus public transport), residential location, and time of day of travel.

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 modifications do not affect the other estimated parameters.

The estimated parameters 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 presented in our supplement. We note here that 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.[3] 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 normally distributed, for travel time, travel time uncertainty, and the HOV2 and HOV3 dummies.

[3] 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.

Based on the estimated coefficients, the value of median travel time is 85% of the hourly wage and the value of reliability is 90% of the hourly wage (see the supplement), which indicates that highway service quality is important to motorists because those values are at the high end of previous estimates summarized in Miller (1989) and Small and Verhoef (2007). Motorists' preferences for speedy and reliable travel vary widely, 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.[4]

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). Currently, U.S. highways are mainly funded by federal and state gasoline taxes, averaging \$0.49 per gallon. We assume that private highways are funded solely by toll revenues and that motorists using those highways do not have to pay gasoline taxes, 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:

$$\delta_0 = \bar{\delta} + \hat{\delta} \cdot E. \tag{9}$$

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 $\left(N, \lambda, \bar{\delta}, \text{ and } \hat{\delta}\right)$, 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.[5] 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 min; the elasticity of travel with respect to the full cost of travel (including the toll and the value of travel time and unreliability) is −0.36; and the elasticity of travel with respect to the driving costs is −0.3.[6]

2.3. 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:

$$T_r = t_f L_r \left(1 + 0.15\left(\frac{V_r}{K_r}\right)^4\right), \tag{10}$$

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.[7] As in SWY, we draw on actual travel on the free lanes and measure travel time uncertainty on route r by specifying it as a constant fraction of travel time delay (travel time minus free-flow travel time) denoted as ΔT_r. Based on travel that is averaged during 5:00 a.m. to 9:00 a.m, we obtain:

$$R_r = 0.3785 \cdot \Delta T_r. \tag{11}$$

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 traffic on an urban interstate highway is \$0.001 per vehicle mile. Based on the circumstantial evidence noted earlier, we assume that pavement maintenance costs are reduced 20% under privatization and we specify the private firm's operating cost (C) as:

$$C = F + 0.0008 \sum_r V_r L_r, \tag{12}$$

where F is the fixed component of operating cost. The assumed reduction in maintenance costs has little effect on our findings because auto's effect on maintenance costs is so small.

General assumption 2. The primary externalities we consider in the analysis are congestion and road damage caused by automobiles, which account for roughly 95% of highway vehicle miles. We simplify the analysis by not assessing pavement damage from heavy trucks, which can range from \$0.01 per vehicle mile to \$0.40 per vehicle mile, depending on the truck's weight and axle configuration, and the social costs of vehicle accidents and emissions.

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. 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.[8]

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 paid. Formally, a private firm

[4] Because the random coefficients of utility are assumed to be normally distributed, the implied values of time are assumed to be normally distributed conditional on household income and trip distance. SWY tried log-normal and truncated normal distributions, but similar to others (Train, 2001) such a model was unable to obtain convergence. The normality assumption means that some travelers may have a negative value of time, which is not necessarily implausible because some motorists may prefer trips that take longer so they can avoid a certain meeting at work or reflect on personal or work-related matters before arriving at their workplaces. In any case, we found that only 15% of motorists in our sample had negative values of time, especially those with the longest trips. Moreover, we found in sensitivity tests that substantially reducing the heterogeneity in the value of time to virtually eliminate the existence of negative values of time in our policy simulations did not affect our main findings about the welfare effects of privatization.

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

[6] 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 and is consistent with a recent estimate by Burger and Kaffine (2009). Sensitivity analyses indicated that our central findings are not particularly sensitive to the assumed values of the elasticities.

[7] Our findings were not particularly sensitive to assuming powers of the volume-capacity ratio that were somewhat higher or lower than four. The formula in Eq. (10) assumes trip timing is exogenous; as noted, we discuss the implications of that assumption in our conclusion.

[8] This assumption is likely to 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.

is willing to buy the highway if the present discounted value of lifetime operating profits (PVP) covers the initial cost of acquiring the infrastructure:

$$\sum_{t=0}^{+\infty} \delta^t \pi_t = PVP \geq I, \tag{13}$$

where δ is the discount factor and π_t is the operating profit at time period t. This condition characterizes the *firm's participation constraint*.

2.4. Government behavior

We analyze the government's behavior with and without toll regulation. In either case, government is assumed to maximize welfare given by the sum of consumer surplus and the private firm's operating profits:

$$W(p_{r1}, p_{r2}) = \theta CS(p_{r1}, p_{r2}) + (1-\theta)\pi(p_{r1}, p_{r2}), \tag{14}$$

where p_{r1} and p_{r2} are tolls on the two routes and the price of alternative j is obtained by dividing the toll on the route by vehicle occupancy; $\pi(p_{r1},p_{r2})$ denotes the operating profits accruing to the private operator given the toll, $CS(p_{r1},p_{r2})$ is the expected change in consumer surplus given in Eq. (8), and θ is a welfare weight. The first-best benchmark does not introduce any constraints on government's pricing behavior and sets $\theta = 0.5$. In practice, complex political economy constraints may affect government's behavior in setting the sale price of the road and in implementing toll regulation; we make assumptions to capture those constraints but do not derive them from a formal political economy model.

General assumption 3. We assume the government maximizes welfare subject to a plausible politically-motivated participation constraint noted below and to the private firm's participation constraint.

Historically, U.S. government regulation of transportation has set regulated prices that favor one group of users over another group (e.g., regulated airline fares increased per-mile as trip distance increased) but have often prevented firms from offering different prices and service to different consumers (e.g., shippers could not pay regulated motor carriers higher rates for more reliable service). Indeed, one of economic deregulation's major benefits was that firms were able to introduce price–service packages to cater to different types of customers (Winston, 1998).

In our two-route network, it is unlikely that government regulation would discriminate between users of the same highway because of perceived administrative complexities of setting differentiated tolls and because of political pressure to offer a free option if differentiated–but regulated–highway services are offered (e.g., such an option made HOT lanes politically feasible). Government regulations in public–private partnerships have in fact prevented private highway operators from setting differentiated prices.

General assumption 4. We therefore assume regulation takes the form of a uniform toll; that is, $p_{r1} = p_{r2} = p$ under government regulation.

The government must satisfy a politically acceptable reservation price for the highway, I^0, that is assumed to cover construction costs; we refer to it as the *government's participation constraint*. Evidence from Indiana's recent sale of its toll road to a private operator indicates that the government is unlikely to encounter information problems that prevent it from satisfying its participation constraint.

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.

When the government does not regulate tolls, it maximizes welfare by choosing a sale price to transfer the highway to a private operator(s) and that price is assumed to extract the private operator's excess operating profits subject to the firm's and the government's participation constraints.

2.5. Private operator behavior

When tolls are not regulated, the private highway operator's objective is to charge prices (tolls) and when possible, to allocate road capacities to maximize the present value of its future profits. Because current decisions are not likely to affect future decisions, we can express the dynamic problem as a series of identical static problems and express Eq. (13) as $(1-\delta)^{-1}\pi \geq I$. 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 forms of competition, such as private duopoly, because the two routes are perfect substitutes 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 price negotiations between users and the monopolist to limit monopoly power. The negotiations would presumably be based on an assumed travel growth; we explore that effect in a sensitivity analysis.

2.6. Equilibrium

The analysis of highway privatization can be formulated as a sequential-moves game. With regulation, the government sets both the sale price of the infrastructure and the toll on the highway in the first stage, and travelers choose alternatives to maximize their utilities given the toll in the second stage and those choices determine travel times and travel time uncertainties. Without regulation, the government sets the sale price of the infrastructure in the first stage; the highway operator sets prices and, when possible, allocates capacity in the second stage; travelers choose alternatives in the third stage. Equilibrium is thus 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 last stage is a *Wardrop Equilibrium* (Wardrop, 1952), which can be obtained as the limit of a sequence of *Nash Equilibria* of games as the number of players goes to infinity (Haurie and Marcotte, 1985). Denote p_j as the price of alternative j and $\mathbf{p} \equiv (p_1,\ldots,p_J)$ as the price vector; the market share vector $S^*(\mathbf{p}) \equiv \left(S_1^*(\mathbf{p}),\ \ldots, S_J^*(\mathbf{p})\right)$ denotes the Wardrop Equilibrium given $\mathbf{p} \geq 0$. In the supplement, we show that a unique Wardrop Equilibrium exists for a price vector $\mathbf{p} \geq 0$.

Moving backward, equilibrium in the previous stage depends on regulation and the competitive environment; we formulate those environments mathematically in the next section. We note here that if tolls are regulated by the government, the government takes users' preferences into account and sets a sale price I and a toll p to maximize welfare subject to its and the operator's participation constraints. The solutions along with the users' Wardrop equilibrium given the toll constitute the SPE to the overall game under regulation.

Without regulation, if both routes are sold to a private firm (monopoly), the firm takes users' preferences into account and allocates capacity between the two routes and sets tolls to maximize profits subject to its participation constraint. If the two routes are sold to different firms with the allocation of capacity pre-determined (duopoly), each firm takes users' preferences into account and engages in price competition by setting profit-maximizing tolls on its route subject to its participation constraint. Under monopoly and duopoly, bilateral negotiations between motorists and the firm(s) to determine tolls yield bargaining solutions that enable both parties to not be worse off compared with the initial case of no-toll. If the government privatizes only one of the routes (public–private duopoly) with predetermined capacities, the two operators in the second stage take users' responses into account and set tolls to maximize their objectives subject to their participation constraints. Given the government's sale price for the infrastructure, the equilibrium prices and allocation of capacity in the second stage together with the Wardrop equilibrium given those prices and allocation of capacity constitute the SPE to the subgame.

In the first stage, the government takes account of the outcomes from the subgame in later stages and sets the sale price for the infrastructure to redistribute the private operators' rents to travelers subject to its participation constraint. The resulting sale price along with the SPE at later stages given the sale price constitutes the SPE to the overall game without regulation.

In the supplement, we describe how we compute equilibrium to the game with and without toll regulation.

3. Regulation and competition scenarios

Highway privatization's economic effects will depend on the regulatory and competitive environment. Engel et al. (2001) motivate the case where the government introduces toll regulation by choosing the welfare maximizing toll when it sells the infrastructure to a private firm and the firm is compensated with the toll revenues. The justification for government regulation depends on the competitive environment for highway services; thus, as an alternative to regulated tolls, we analyze tolls that are determined under monopoly, duopoly, and public–private competition with and without negotiations with motorists. In the supplement, we present graphical solutions to show the existence of equilibria in the cases of duopoly and public–private competition with and without bargaining. Mathematical formulations of the regulation and competition scenarios are as follows.

3.1. Government regulation

Under regulation, government's welfare maximization problem is:

$$\max_{I,p} \sum_{t=0}^{+\infty} \delta^t W(p) = \frac{W(p)}{1-\delta}$$
$$s.t. \frac{\pi(p)}{1-\delta} - I \geq 0 \qquad (15)$$
$$I \geq I^0,$$

where $W(p)$ is welfare and $\pi(p)$ is the operator's profits at the Wardrop equilibrium given the regulated toll p. Given the firm's and government's participation constraints, the actual toll could deviate from the optimal congestion toll p^*.

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 Eq. (15) given that the operator's participation constraint is binding at I^0. Given the government's welfare "weights," it could take a simpler approach by defining welfare solely in terms of consumer surplus and determining the welfare maximizing toll and sales price subject to the firm's and its participation constraints.

3.2. 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

$$\pi(K_{r1}, K_{r2}, p_{r1}, p_{r2}) = \sum_{m \in (r1, r2)} V_m(K_{r1}, K_{r2}, p_{r1}, p_{r2}) \cdot p_m - C(K_{r1}, K_{r2}, p_{r1}, p_{r2}), \qquad (16)$$

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

$$\max_{(K_{r1}, K_{r2}, p_{r1}, p_{r2})} \sum_{t=0}^{+\infty} \delta^t \pi(K_{r1}, K_{r2}, p_{r1}, p_{r2}) = \frac{\pi(K_{r1}, K_{r2}, p_{r1}, p_{r2})}{1-\delta}$$
$$s.t. \frac{\pi(K_{r1}, K_{r2}, p_{r1}, p_{r2})}{1-\delta} - I \geq 0 \qquad (17)$$
$$K_{r1} + K_{r2} = K$$

where K is the total capacity of the highway.[9] Without the participation constraint, the firm obtains the monopoly profit-maximizing solution denoted by $(K_{r1}^M, K_{r2}^M, p_{r1}^M, p_{r2}^M)$.

As noted, the government's sale price seeks to extract excess operating profits. Thus, if $\frac{\pi(K_{r1}^M, K_{r2}^M, p_{r1}^M, p_{r2}^M)}{1-\delta} - I^0 > 0$, the sale price satisfies $\frac{\pi(K_{r1}^M, K_{r2}^M, p_{r1}^M, p_{r2}^M)}{1-\delta} - I = 0$; otherwise, the government's sale price is I^0 and the monopoly's allocation of capacity and tolls satisfy Eq. (17) given the participation constraint $\frac{\pi(K_{r1}, K_{r2}, p_{r1}, p_{r2})}{1-\delta} = I^0$.

The problem in Eq. (17) assumes that travelers have no negotiating power in setting tolls; thus, solutions to 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, and the firm. A third-party advocate is necessary because coordination by individual motorists to form a bargaining unit is likely to be prohibitively costly. And although motorists do not have uniform preferences, a third party should be able to avoid coordination problems and account for basic preference heterogeneity as, for example, currently reflected by users of regular lanes and HOT lanes by negotiating price-capacity packages that cater to travelers with a high value of travel time and reliability and to travelers with a lower value of time and reliability. 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. However, we do not fully characterize the bargaining problem—specifically; we do not determine how the third-party advocate aggregates motorists' preferences, how the parties credibly identify outside options, and how a party forms a sensible "blocking coalition."

General assumption 5. Instead, we assume bargaining between a third-party advocate and the private operator can and does take place and we analyze extreme solutions that favor one of the parties as well as interior solutions that may yield a win–win outcome.

The extreme outcomes of the bargaining solution include the *operator's solution*, where the monopolist maximizes profits subject to the additional constraint that the change in consumer surplus is nonnegative, and the *travelers' solution*, where travelers maximize consumer surplus subject to the firm earning non-negative profits. A bargaining solution may include or lie between those extreme cases

[9] Treating capacity decisions as endogenous should not pose problems in the case of highway privatization because we are primarily concerned with allocating traffic lanes. For example, 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.

and can be expressed as the solution to the problem in Eq. (17) with the additional consumer surplus constraint that $CS(K_{r1},K_{r2},p_{r1},p_{r2}) \geq s$, where $CS(K_{r1},K_{r2},p_{r1},p_{r2})$ is the consumer surplus change at the Wardrop equilibrium given the tolls and capacity allocation; $s \in [0, \bar{s}]$ represents the travelers' bargaining power and its upper bound, $\bar{s}$, is the change in consumer surplus in the travelers' solution.

Let $(K^B_{r1},K^B_{r2},p^B_{r1},p^B_{r2})$ denote the bargaining solution without the operator's participation constraint. If $\frac{\pi(K^B_{r1},K^B_{r2},p^B_{r1},p^B_{r2})}{1-\delta} > I^0$, the government's optimal sale price of the highway satisfies $\frac{\pi(K^B_{r1},K^B_{r2},p^B_{r1},p^B_{r2})}{1-\delta} = I$; if $\frac{\pi(K^B_{r1},K^B_{r2},p^B_{r1},p^B_{r2})}{1-\delta} \leq I^0$, 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.

3.3. 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 does not sell the routes to the firms at different prices; that is, $I_{r1} = I_{r2}$.

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

$$\begin{aligned} &\max_{p_{r1}} \sum_{t=0}^{+\infty} \delta^t \pi_{r1}(p_{r1},p_{r2}) = \frac{\pi_{r1}(p_{r1},p_{r2})}{1-\delta} \\ &s.t. \frac{\pi_{r1}(p_{r1},p_{r2})}{1-\delta} - I_{r1} \geq 0 \\ &I_{r1} \geq I_0 / 2. \end{aligned} \tag{18}$$

$\pi_{r1}(p_{r1},p_{r2})$ is the operator's profits at the Wardrop equilibrium given the tolls and capacity allocation. The solution to the problem, denoted by $p_{r1} = f_{r1}(p_{r2})$, is the toll schedule with respect to p_{r2}. Similarly, the operator of route $r2$ solves:

$$\begin{aligned} &\max_{p_{r2}} \sum_{t=0}^{+\infty} \delta^t \pi_{r2}(p_{r1},p_{r2}) = \frac{\pi_{r2}(p_{r1},p_{r2})}{1-\delta} \\ &s.t. \frac{\pi_{r2}(p_{r1},p_{r2})}{1-\delta} - I_{r2} \geq 0 \\ &I_{r2} \geq I_0 / 2. \end{aligned} \tag{19}$$

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 and require operators to commit to a toll. 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 Eq. (18) by choosing the profit-maximizing toll given the price on route $r2$. The operator of route $r2$ then solves the problem in Eq. (19) with the additional constraint that $p_{r1} = f_{r1}(p_{r2})$.

We denote the equilibrium prices of duopoly competition (either Bertrand or Stackelberg) by (p^D_{r1},p^D_{r2}) 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 $(I_{r1} = I_{r2} = I_0/2)$ and the duopoly equilibrium is determined by the solutions to Eqs. (18) and (19) 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.

3.4. 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 such that the private and public operators set tolls simultaneously or the government sets the toll on route $r2$ first. The alternatives are the same as those in private duopoly competition with the only differences that the public operator's objective is to maximize net benefits, as defined above, and that it does not face a 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.

4. Findings

In the simulations, we make the standard assumption that road capacity is 2000 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 min implying a speed of 30 mph, 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 one-period and present value of operating profits, and the one-period change in the government's budget, consumer surplus, and social welfare.[10] 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.

4.1. 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 first 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 (i.e., $\theta = 0.5$ in Eq. (14)) or to maximize only consumer surplus ($\theta = 1.0$).

[10] 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.

Table 1
Welfare effects under government regulation (with the gas tax rebate).[a]

	Base case: current situation	Government maximizes only consumer surplus	Government maximizes the sum of consumer surplus and operating profits	First best
Capacity (vehicles/h)				
Route $r1$	6000	6000	6000	2000
Route $r2$	6000	6000	6000	10,000
Sale price ($ million/mile)	N.A.	12.0	49.4	39.2
Toll ($)				
Route $r1$	0.00	1.69	9.31	0.00
Route $r2$	0.00	1.69	9.31	9.84
Travel times (min)				
Route $r1$	20.00	19.12	12.33	59.35
Route $r2$	20.00	19.12	12.33	11.29
Aggregated choice shares (%):				
No travel on the corridor	8	6	7	6
Travel on the corridor	92	94	93	94
For those who travel on the corridor				
Solo driving	80	74	37	46
HOV2	17	21	43	38
HOV3	3	5	20	16
Operating profits: one period ($/person) [b,c]	0.00	0.89	3.66	2.91
Operating profits: present value ($ million/mile)[d]	0.00	12.0	49.4	39.2
Change in gov't budget: one period ($/person)[c,e]	0.00	0.67	3.44	2.79
Change in consumer surplus: one period ($/person)[c]	0.00	0.52	−1.87	0.57
Change in social welfare: one period ($/person)[c,f]	0.00	1.19	1.57	3.36

[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 1 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 on highways because, on average, motorists would be worse off (Mohring, 1999), any proposed change in highway policy would be more likely to gain widespread political support if, on average, it benefitted motorists. Motorists are able to gain if tolls are set to maximize consumer surplus because the improvement in travel time and the rebate or elimination of gasoline taxes exceeds the modest toll. Specifically, the $0.52 gain in consumer surplus per person consists of a gain of $0.38 from faster travel time and greater reliability and of $1.52 from the gas tax rebate and a loss of $1.38 from the toll. To conserve space, we do not break down the components of the change in consumer surplus when we present other findings, but in general the sources of a gain in consumer surplus to motorists parallel those in this scenario. The breakeven level of the toll generating zero profits for the operator 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.[11] 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. The first-best outcome (Eq. (14) in the final column with $\theta = 0.5$) calls for product differentiation with one route charging a high toll on five lanes that offer significant travel time savings and the other route providing an untolled lane with much slower travel time. The social welfare gain is much greater than in the preceding cases because the government's budget significantly improves and motorists' consumer surplus increases.

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 unless it sets differentiated tolls for the two routes to achieve the first-best outcome. Because we have indicated that government is highly unlikely to set differentiated tolls and 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.

4.2. 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.[12]

4.2.1. Monopoly

As shown in Table 2, 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 has been substantially

[11] 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.

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

Table 2
Welfare effects under monopoly provision (with the gas tax rebate).

	Base case: current situation	Monopoly	Monopoly bargaining: travelers' solution	Monopoly bargaining: operator's solution	First best
Capacity (vehicles/h)[a]					
Route r1	6000	6000	2000	2000	2000
Route r2	6000	6000	10,000	10,000	10,000
Sale price ($ million/mile)	N. A.	63.6	12.0	42.8	39.2
Toll ($)					
Route *r*1	0.00	22.14	0.00	1.59	0.00
Route *r*2	0.00	22.14	2.19	10.55	9.84
Travel times (min):					
Route *r*1	20.00	9.50	34.43	50.10	59.35
Route *r*2	20.00	9.50	17.62	10.97	11.29
Aggregated choice shares (%):					
No travel on the corridor	8	31	5	7	6
Travel on the corridor	92	69	95	93	94
For those who travel on the corridor					
Solo driving	80	8	74	41	46
HOV2	17	50	21	40	38
HOV3	3	42	5	19	16
Operating profits: one period ($/person)[b,c]	0.00	4.71	0.89	3.17	2.91
Operating profits: present value ($ million/mile)[d]	0.00	63.6	12.0	42.8	39.2
Change in government budget: one period ($/person)[c,e]	0.00	4.49	0.67	2.95	2.79
Change in consumer surplus: one period ($/person)[c]	0.00	−6.33	1.40	0.00	0.57
Change in welfare: one period ($/person)[c,f]	0.00	−1.84	2.07	2.95	3.36

[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] 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.

reduced and little congestion exists.[13] 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 motorists are represented by a firm or association that negotiates tolls with the private operator.[14] 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 min and the other lane has no toll and a travel time of 34.4 min. 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, high-income motorists will not be the only highway users who benefit from being able to travel on the express toll lanes. In fact, 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.[15]

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 monopolist pays a much higher price for the road, thereby significantly improving the government's budget. The overall gain in welfare is still higher under the first-best outcome presented in the last column; but, interestingly, motorists' welfare is higher in the travelers' solution because the price-service tradeoff is better aligned with their preferences than is the tradeoff under the first-best outcome that explicitly accounts for the operator's profit instead of treating it as a constraint.

In the supplement, we present a scenario that accounts for traffic growth and shows that the travelers' solution yields a much more differentiated toll in response to greater congestion and produces a social welfare gain that exceeds the gain produced by the operator's solution. The supplement also presents figures that indicate that a wide range of negotiating outcomes–not just a polar outcome–could enable both the private operator and motorists to gain from privatization.

[13] 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.

[14] 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.

[15] Express toll lanes have been characterized as "Lexus lanes," but the Washington State Department of Transportation collected data on the users of their HOT lanes, on SR 167, and found that the four luxury brands (Acura, BMW, Lexus, and Mercedes) accounted for less than 7% of toll-paying vehicles.

Table 3
Welfare effects under duopoly provision (with the gas tax rebate).

	Base case: current situation	Bertrand competition without bargaining [a]	Bertrand competition with bargaining: travelers' solution [a]	Bertrand competition with bargaining: travelers' solution (two equilibria)	
Capacity (vehicles/h)[b]					
Route *r*1	6000	6000	6000	4000	
Route *r*2	6000	6000	6000	8000	
Sale Price ($ million/mile)					
Route *r*1	N. A.	25.5	6.0	4.0	
Route *r*2	N. A.	25.5	6.0	8.0	
Toll ($)					
Route *r*1	0.00	10.25	6.11	7.55	1.58
Route *r*2	0.00	9.84	1.58	1.63	4.22
Travel times (min):					
Route *r*1	20.00	11.61	13.86	12.74	23.79
Route *r*2	20.00	12.26	22.17	20.61	15.84
Aggregated choice shares (%):					
No travel on the corridor	8	8	5	5	5
Travel on the corridor	92	92	95	95	95
For those who travel on the corridor					
Solo driving	80	33	64	64	67
HOV2	17	45	27	27	26
HOV3	3	22	9	9	7
Operating profit: one period ($/person)[c]					
Route *r*1	0.00	1.89	1.32	1.02	0.30
Route *r*2	0.00	1.92	0.45	0.59	1.34
Operating profits: present value ($ million/mile)[d]					
Operator *r*1	0.00	25.5	18.0	13.8	4.0
Operator *r*2	0.00	25.9	6.0	8.0	18.1
Change in government budget: one period ($/person)[c,e]	0.00	1.67	0.23	0.37	0.08
Change in consumer surplus: one period ($/person)[c]	0.00	−2.14	0.65	0.92	0.51
Change in social welfare: one period ($/person)[c,f]	0.00	1.45	2.20	2.31	1.93

[a] Another equilibrium is obtained by switching the tolls on the two routes.
[b] 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 Appendix A.
[c] 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*.
[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 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] 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.

4.2.2. Duopoly

Policymakers may oppose 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 3, duopoly competition (Bertrand) sharply reduces tolls from monopoly provision, reduces the loss to motorists, and improves welfare.[16] But 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. 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.

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 untolled lane while a duopolist cannot because it will not break even.[17] Thus in a privatized highway market, motorists may be potentially better off negotiating with a monopoly than with a duopoly. In the supplement, we strengthen this conclusion by showing that a monopoly would be more likely than a duopoly to add capacity (an additional lane) that would raise consumer surplus.[18] Finally, a monopoly highway firm has some operating advantages over duopolists because it is better able to exploit scale economies in toll collection, it would not have to

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

[17] 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 supplement for details.

[18] The supplement presents outcomes with different bargaining solutions. Those solutions should be qualified because it is possible that the initial bargaining solution that was obtained before the decision to add capacity was considered will have implications for future investment resulting in a hold-up problem that creates dynamic inefficiencies. The issue merits further attention in future work on highway privatization that studies capacity expansion in greater detail.

Table 4
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/h)[a]				
Route $r1$ (private)	6000	2000	2000	2000
Route $r2$ (public)	6000	10,000	10,000	10,000
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.

coordinate its toll collection transponder technology with another firm, and it could easily provide consistent signage.

4.2.3. 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.

As indicated in Table 4, 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).[19] 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 rebate the gasoline tax, which would be justified because the government is still operating most of the highway.

[19] 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.

5. Discussion and qualifications

We conclude that highway privatization is a potentially attractive policy if the private operator's pricing and capacity decisions are responsive to motorists' heterogeneous preferences. As we show in the supplement, the failure to respond to those preferences prevents motorists' welfare from improving under privatization because the undifferentiated toll is too low to generate sufficient service time benefits to travelers with high values of time and reliability but high enough to harm travelers with lower values of time.

We have conducted our analysis using a sample 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 being willing to pay large sums to improve travel time and reliability.

Another qualification is that we analyzed travelers' and operators' behavior on a road system of parallel lanes that is conducive to privatization because the lanes are perfect substitutes and facilitate competition in duopoly regimes. A complex network of roads could also be privatized effectively in the bargaining environment that we envision by permitting coordination between independent highway operators or by allowing a single operator control over multiple links. The approach taken by Verhoef (2002) is a useful starting point for analyzing pricing in a network of roads.

It is also important to assess our findings in light of the five general assumptions we have made. We have focused on inefficiencies associated with current road pricing and capacity allocation, and to a limited extent, with current road maintenance policies. Privatization is also likely to reduce highway production costs, including the pavement damage caused by truck traffic, and to spur innovation in highway services, which would benefit all road users. 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 their pavement costs (Small et al., 1989). The public sector has failed to adopt efficient pricing and investment policies to reduce motor carriers' highway costs, but a profit-maximizing highway operator would have an incentive to adopt such policies; thus, it is likely that we have understated the benefits of privatization by not including trucks in the analysis (General assumption 2). We may have also understated benefits because the private sector is likely to have a greater incentive than the public sector has to reduce delays and the likelihood of litigation related to highway accidents. Accordingly, private highway operators may take greater measures to enhance motorists' safety by, for example, improving the quality of road pavement and lane dividers, signage, lighting, and the like. At the same time, more efficient public policies are necessary to reduce the social costs of vehicle emissions on both public and private roads.

Still another reason why we may have understated benefits is because we have assumed that motorists' route and vehicle occupancy decisions are conditional on their choice of mode, residential and workplace location, and time of trip (General assumption 1). 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 are preventing them from reducing 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 increasing the benefits from faster and more reliable travel by living further from their workplace in lower cost housing as well as by traveling at more convenient times of day.[20]

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 that set consumer welfare maximizing tolls. But we have argued that government regulation is notoriously poor at responding to preference heterogeneity and we have found that this failure in the case of highways, which results from our assuming uniform toll regulation (General assumption 4), would significantly reduce the welfare gains from privatization. If, in fact, the government were capable of setting regulated differentiated tolls that improved motorists' and social welfare, that would enhance the likelihood that some form of privatization could succeed.

At the same time, 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 (General assumption 3). 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.

Finally, we have assumed that a third-party advocate for motorists and the private operator would bargain over tolls and capacity (General assumption 5). Although we have found a range of outcomes that would benefit motorists and improve social welfare, we do not know if such a solution would result in practice.

The uncertainty of 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 indicates that it would be desirable for the government to explore those issues by carefully designing and implementing highway privatization experiments in selected cities that go beyond the restrictive framework of public–private partnerships. Privatization may 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, airports, and office buildings–that could improve their budgets. Such an approach may be particularly attractive for highways because, as noted, the federal highway trust fund has started to run a deficit and it is likely that the growing subsidies would be financed by distortionary taxes.

We have identified some important and plausible features of a private highway market that should be borne in mind when experiments are designed and some uncertainties about the actual outcomes of privatization that experiments could help resolve. Hopefully, future work will provide additional motivation and guidance for policymakers who realize that the time has come to investigate whether the private sector could improve on the public sector's provision of highway services.

Acknowledgments

We are grateful to a long list of colleagues and seminar participants, two referees, and an editor for their helpful comments.

Appendix A. Supplementary material

Supplementary material to this article can be found online at doi:10.1016/j.jpubeco.2011.01.005.

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

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