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Cost recovery from congestion tolls with long-run uncertainty

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ABSTRACT

According to the Cost Recovery Theorem the revenues from optimal congestion tolls pay for the capacity costs of an optimal-sized facility if capacity is perfectly divisible, and if user costs and capacity costs have constant scale economies. This paper extends the theorem to long-run uncertainty about investment costs, user costs, and demand. It proves that if constant scale economies hold at all times and in all states, and if the toll can be varied freely over time and by state, then expected discounted congestion toll revenues cover expected discounted investment costs over a facility's lifetime. If the marginal cost of investment is constant and investment is reversible, expected cost recovery also holds for each investment. If demand is relatively price inelastic, cost recovery is sensitive to estimated initial demand and estimated growth rate of demand. Natural variability in demand can result in substantial surpluses or deficits over a facility's lifetime.

1. Introduction

Herbert Mohring made a number of landmark contributions to transportation economics over his long career. One of his greatest achievements is the self-financing or cost recovery[2] theorem (Mohring and Harwitz, 1962). The theorem states that the revenues from optimal congestion tolls pay for the capacity costs of an optimal-sized facility if capacity is perfectly divisible, and if user costs and capacity costs both have constant scale economies. The theorem is of interest for at least two reasons. First, it establishes that pricing a facility at marginal social cost to support efficient usage may be compatible with pricing the facility at average cost to finance it.[3] Second, the theorem is appealing from a normative standpoint because it shows that efficient pricing is consistent with the user-pay principle: there is no need to subsidize users, and users do not have to pay more than costs for the services they consume. The lack of need for a subsidy is especially attractive given the chronic shortage of funds for investment in, and operations of, public facilities.

Mohring and Harwitz derived their theorem for a deterministic environment. Yet uncertainty[4] is practically important for many transportation and other facilities. In the case of roads, demand and capacity fluctuate unpredictably from day to day due to weather, accidents, unplanned road maintenance, and so on. Lindsey (2009) shows that the theorem continues to hold in the face of such short-run fluctuations if two additional assumptions are imposed: individuals learn supply and demand conditions before deciding whether to use a facility, and the congestion toll is varied *responsively* to maintain efficient usage levels.

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[2] The terms “self-financing” and “cost recovery” will be used interchangeably in this paper.

[3] Some prominent economists at the time, including Beckmann et al. (1956) and Nelson (1962), had expressed doubts that the goals of efficient usage and cost recovery could be reconciled. Indeed, the tension between the two goals dates back to Jules Dupuit and Arthur Pigou. For a historical review see Lindsey (2006).

[4] Since the probabilities of states are assumed to be known in our model we actually deal with risk rather than uncertainty. Despite this, we use the term uncertainty since this is standard in the related literature.

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Nomenclature

$A_i(\,)$	investment cost function
$C_{tw}(\,)$	user cost function at time t in state w
E^i	expectations operator at time T_i
$f^i(t, w)$	probability density of state w at time t perceived at time T_i
h	composite parameter (specific dynamic model)
I_i	capacity investment at time T_i
k	unit cost of investment (specific dynamic model)
m	composite parameter (specific dynamic model)
M	number of investments (can be finite or infinite)
$N_{tw}(\,)$	demand function at time t in state w
p_{tw}	full price or generalized cost of usage at time t in state w
$p(N)$	inverse demand function (static model)
$r(t)$	instantaneous discount rate at time t
t	time
R	toll revenue
$\hat{s}_i$	design capacity at time T_i
s_{tw}	capacity realized at time t in state w
T_i	time of investment i
W	welfare

Greek characters

Γ_t	Cumulative discount rate at time t
ε^i_{tw}	elasticity of realized capacity s_{tw} with respect to design capacity $\hat{s}_i$ for $t \in [T_i, T_{i+1})$
ε^R_s	elasticity of toll revenue with respect to design capacity
ε^ρ_s	elasticity of cost recovery ratio with respect to design capacity
η	demand elasticity (specific dynamic model)
λ	composite parameter (specific dynamic model)
μ_i	multiplier for capacity accumulation constraint at time T_i
ξ	rate of technological progress (specific dynamic model)
ρ	fraction of capacity cost recovered by toll revenue
τ_{tw}	toll at time t in state w
ϕ_i	multiplier for nonnegative investment constraint at time T_i
w	state
$\mathfrak{I}$	Lagrangian

Unlike Lindsey (2009), this paper is concerned with uncertainty about investment costs, user costs, and demand over a facility's lifetime rather than with short-run capacity and demand fluctuations. It addresses two major questions about cost recovery. First and foremost, does the Mohring–Harwitz cost recovery theorem extend to long-run uncertainty in some well-defined and practically relevant sense? Second, how empirically likely are large surpluses or deficits due either to errors and biases in investment decisions or to natural variability in demand and other factors over a facility's lifetime?

Our theoretical treatment of these questions is general, but the focus is on roads. The costs and time required to build, expand, and rehabilitate a road are uncertain. Costs can rise because of changes in technical specifications, new construction methods, demands from municipalities for better network connections, and so on (Nijkamp and Ubbels, 1999; Berechman, 2009). Major cost overruns and delays are common for toll roads. In a large international survey, Flyvbjerg et al. (2003) found an average cost escalation of 20.4% for road projects, and 33.8% for bridges and tunnels.[5]

Road operations and maintenance costs are also unpredictable. Input costs (e.g., labor, fuel, and material) can vary significantly over time. Natural disasters such as earthquakes and hurricanes cause extensive damage. Climate change affects the frequency and severity of extreme weather, flooding, frost heave, and so on. Traffic volumes are also a major source of uncertainty. In another large international survey, Flyvbjerg et al. (2006) found that, for half of road projects, actual traffic deviated from forecasted traffic by more than $\pm 20\%$.[6] Traffic volumes are affected by a host of unpredictable factors: project completion time, economic growth rates, fuel prices, land-use developments, construction of competing or complementary roads, environmental concerns that curb automobile usage, changing preferences with respect to housing and mode choice, and so on.[7]

Despite improvements in data collection and econometric methods, forecasts have not become more accurate over time (Flyvbjerg et al., 2006; Transportation Research Board, 2006). Optimistic demand projections tend to be the norm for toll road projects. Bain (2009) identifies several reasons: lower-than-expected travel time savings; over-estimation of drivers' values of time[8] and corresponding willingness to pay tolls; and errors in designing complex tolling schemes in which tolls vary by vehicle type, section of road, and time of day.

Technology is a third factor that can affect cost recovery over a road's lifetime. Traffic management system techniques such as ramp metering help to regulate demand. Incident Management Systems reduce the duration of traffic incidents. Advanced Traveler Information Systems notify motorists about traffic conditions. Road vehicles are becoming smaller, smarter, and safer. Vehicle collision avoidance systems, lane-departure warning systems, driver fatigue monitoring systems, heads-up displays, and improved braking systems are reducing the probability of accidents that contribute to congestion. By increasing effective road capacity, and managing demand, these technologies help to improve the utilization of roadways.[9]

A final influence on capacity and cost recovery is flexible road capacity design. The capacity of existing roads can be increased or decreased by re-striping lanes, allowing vehicles to use shoulders during peak periods, changing speed limits, introducing or eliminating features to accommodate public transit and/or bicycles, and so on (Ng and Small, 2012). The appropriate date at which to make these adjustments depends on traffic volumes, ITS technology and vehicle designs, and is therefore unpredictable.

The paper is organized as follows. Section 2 reviews the theoretical literature. Section 3 sets out the model. Section 4 presents two versions of a cost recovery theorem with long-run uncertainty. Section 5 examines the prevalence of surpluses and

[5] Other studies of cost overruns include Odeck (2004) and Berechman and Chen (2011).

[6] Other studies of bad forecasts include Prozzi et al. (2009) and Williams-Derry (2011).

[7] Lindsey (2012) discusses the future evolution of road travel demand.

[8] See Hensher and Goodwin (2004).

[9] As evidence, capacity values in the US Highway Capacity Manual have increased over time (Elefteriadou, 2004).

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