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Time Consistency of Congestion Tolls

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Abstract

Consider users who can choose between using two modes of travel (say a road and mass transit), and who can choose to incur a fixed cost that reduces the future costs of using mass transit. A congestion toll on the road may serve two purposes. First, it can induce users in the current period to use transit instead of the congested road. Second, users who anticipate the imposition of tolls may be induced to incur the aforementioned fixed cost, thereby reducing demand for use of the congested road in future periods. This paper focuses on such investment decisions, showing that when government cannot credibly commit to future tolls, the optimal road toll in each period may be low and congestion may be high.

Introduction

Most analyses of how tolls can solve congestion problems are static, ignoring the consequences of government's incentives to change a toll (see Walters, 1961; Weitzman, 1974; Small,1992, pp.107-25; National Research Council, 1994; and Verhoef,1996). Static analysis is appropriate if the demand for travel or the costs of travel (exclusive of tolls) cannot change over time. But, as I intend to show, dynamics matter greatly if consumers can make a costly investment in some period that changes the opportunity cost of using the congested road in later periods. Standard analyses therefore do not see policy as potentially subject to problems of credibility or of time inconsistency. I here address these issues, and give one explanation for the rare imposition of tolls. My explanation can complement other explanations for the non-imposition of tolls. One explanation rests on the theoretical result that if all consumers suffer identically from a delay, and if the toll revenue is not returned to consumers, then they necessarily suffer (see Weitzman, 1974). A different explanation rests on the empirical observation that the people who choose to use a congested road are consumers who little value time, and therefore would gain little from reduced congestion (Calfee and Winston,1998).

Like many other analyses, my model supposes that each consumer can choose between two modes, with the first mode (say, a road) congestible and the second mode (say, mass transit) not. I extend earlier work in two ways. First, I suppose that in any period each consumer can choose to take some costly action that increases the utility he would obtain in all later periods from using the second mode. For succinctness I shall call such an action an investment. Examples of the costs that may be involved include the time and effort required to work out a bus schedule, the cost of moving closer to a train station, or the lower wage earned on switching to a job that allows commuting at off-peak periods.

Second, I suppose that government cannot commit to the road tolls it will set in the future, but rather sets a toll in each period that maximises social welfare in that period. The inability to commit means that if consumers avoid the investments that increase the attractiveness of the second mode, then in each period government may impose a low toll on the road, which in turn gives consumers little incentive to make these investments.

Critical to the analysis, therefore, is the issue of credibility or of time inconsistency: is the toll that maximises social welfare in any one period the same as the toll that maximises welfare when it can be imposed in all periods? The essential idea that policy may not be credible appears in works on trade protection (see Staiger and Tabellini, 1987; Matsuyama, 1990; and Tornell, 1991). The discussion of commitment in public policy relates to work by Strotz (1955-56), Kydland and Prescott (1977), Barro and Gordon (1983), and Persson (1988).

They show that current decisions of economic agents depend, in part, on their expectations of future policy. Phelps and Pollak (1968) apply the principle to determine optimal savings decisions. Alesina and Tabellini (1988) and Tabellini and Alesina (1990) extend these insights by showing that voters may favour budget deficits that constrain future public policy. Glazer (1989) applies these principles to demonstrate that collective choices will show a bias towards durable projects.

Related studies examine how expectations of a change in policy may change behaviour in a way that increases political support for the policy under consideration. Cassing and Hillman (1986) show that a declining industry may suddenly collapse when its small size reduces political support for protective tariffs. Obstfeld (1986) shows that a balance-of-payments crisis can be self-fulfilling if agents expect a speculative attack to set off an inflationary domestic-credit policy. Rodrik (1991) claims that trade liberalisation will succeed if it induces the growth of firms that support such liberalisation.

Assumptions

Congestion
I start with a standard model of congestion. Let the number of people using the congested mode, the road, in some period be q. The cost per person of making a trip on that mode is $C(q)$; total social cost is $qC(q)$. Marginal social cost is

$$MSC(q) \equiv \frac{d[qC(q)]}{dq} = qC'(q) + C(q). \qquad (1)$$

If $C'(q) > 0$ then marginal social cost is greater than $C(q)$, the cost per person.

Consumers
The benefit to consumers of using the road is described by the inverse demand function $P(q)$ with $P'(q) < 0$. That is, consumers are ordered by decreasing willingness to pay. When q people use the road, the net benefit to consumer x is $P(x) - C(q)$. Each consumer can use a second, alternative, mode; use of that mode by a consumer who had not invested gives reservation utility of $\bar{u}$, with utility measured in the same units as cost. A consumer can make an irreversible investment at cost K. The horizon is infinite; the intertemporal discount rate is r. The investment pays off in each following period. To highlight the problems of

time-inconsistency, I suppose that an investment generates no benefits in the current period. (That is also a reasonable assumption: for example, a person may decide now to buy a house closer to his job, but will only be able to move in after three months.) The benefit from the investment consists of increasing the utility of using the second mode by s, with $s > rK$. The total number of consumers is n.

The consumer's problem examined here is commonplace. It is the same that appears when a car owner decides whether to buy a diesel-powered car to avoid paying petrol taxes. He will find the purchase worthwhile only if he expects government to tax petrol at a higher rate for many periods in the future.

To highlight the results and to simplify the analysis I suppose that an externality exists on only the first mode; the second mode is not congestible. For simplicity, I also suppose that utility from use of the road depends only on congestion, and cannot be increased by any investment.

Suppose that before period 1 tolls were infeasible, and consumers expected that no tolls would ever be imposed. Consumers, however, still had to decide whether to invest. A consumer who had invested in some period and intended to use the second mode thereafter had expected discounted utility of $-K + (\bar{u} + s)/r$. The number of road users in a Nash equilibrium must therefore satisfy

$$P(q) - C(q) = \bar{u} + s - rK. \qquad (2)$$

This equation simply says that the net private benefit to a consumer is equal on the two modes. Call the value of q that satisfies this equation q_0; the number of people who invest is $n - q_0$.

In period 1 the opportunity to impose a toll in the current and in all following periods unexpectedly arises. In all periods the toll revenue is a pure transfer payment, which does not affect social welfare. Government is restricted to one policy tool: the imposition of a toll on the congestible road. It cannot directly control investments made by consumers.

First-best Policy

Suppose first that government can commit in period 1 to a toll in all future periods. Beginning in period 1, consumers anticipate the toll and invest accordingly. Let the socially optimal number of users on the congestible mode be $q^* < q_0$.

Social welfare is

$$\left(\frac{1}{r}\right)\left[\int_0^{q^*} P(x)dx - q^*C(q^*) + (n-q^*)(\bar{u}+s) - (n-q^*)rK\right]. \quad (3)$$

The first-order condition for a maximum is

$$P(q^*) - q^*C'(q^*) - C(q^*) = \bar{u} + s - rK. \quad (4)$$

This equation simply says that the marginal net social benefit is equal on the two modes.

Diagram

The solution is depicted in Figure 1. The value $\bar{u}$ is a user's utility on the second mode when he had not invested. A consumer who had invested considers utility $s + \bar{u}$ on the second mode when deciding whether to use it.[1] In deciding whether to invest, a consumer considers the utility $s - rK + \bar{u}$. The curve $P(q) - C(q)$ represents the marginal consumer's net utility on the road when the toll is zero. If the socially optimal toll, $qC'(q)$, is imposed, the marginal consumer's net utility on the road is shown by the curve $P(q) - qC'(q) - C(q)$. The number of people using the road is depicted by q, the horizontal distance from the origin. The number of people using the second mode is the distance from some q to n.

Figure 1

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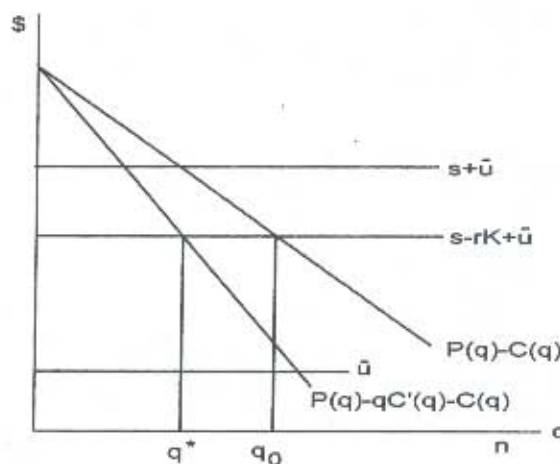
[1]   The investment cost, K, is a sunk, irreversible cost, which, after the investment is made, does not enter the calculation.

In the Nash equilibrium solution with a zero toll, the number of road users is q_0, where the marginal consumer's utility on the road, $P(q_0) - C(q_0)$, equals the highest utility obtainable on the second mode, $s - rK + \bar{u}$. The socially optimal solution is at q^*, where the marginal social benefit to a consumer of using the road, $P(q^*) - q^* C'(q^*) - C(q^*)$, equals a consumer's net utility on the second mode, $s - rK + \bar{u}$.

Time-consistent Policy

Time consistency of first-best policy

Next, consider policy when government cannot commit in any period to the toll charged in any later period. Instead, in each period it takes as given the number of people who had invested, and accordingly sets the toll that maximises social welfare in that period. Recall that investment in some period generates benefits only in later periods; no benefit is obtained in the period in which investment is made, and the toll in the current period does not affect consumers' investment decisions.

Let the number of people who invested before period 2 be $n - q^*$, consisting of $n - q_0$ who invested before period 1, and of $q_0 - q^*$ who invested in period 1. For that to be a time-consistent policy, in each period after period 1 maximising social welfare requires a toll inducing q^* people to use the road.

If one more person is induced to use the road, then the gain in utility from users of the road is $P(q^*) - q^* C'(q^*) - C(q^*)$. The loss in aggregate utility on the second mode is $\bar{u} + s$.[2] So increasing the number of road users (and reducing the number of users on the second mode) reduces social welfare if $P(q^*) - q^* C'(q^*) - C(q^*) < \bar{u} + s$.

Suppose instead that a person is induced to switch from the road to the second mode, reducing the number of road users to less than q^*. Since this person had not invested, his utility on the second mode is $\bar{u}$. So reducing the number of road users (or increasing the number of users on the second mode) reduces social welfare if $P(q^*) - q^* C'(q^*) - C(q^*) > \bar{u}$. Thus, the number of road users government will choose in any period, given that $n - q^*$ had invested, must satisfy

$$\bar{u} < P(q^*) - q^* C'(q^*) - C(q^*) < \bar{u} + s. \tag{5}$$

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[2] The investment cost, K, does not enter because the investment is irreversible.

The standard solution has a toll, t, equal to the difference between marginal social and private cost,

$$t = q^*C'(q^*). \tag{6}$$

We must next check the condition that q^* is a Nash equilibrium with rational expectations. The marginal consumer's utility when he uses the road must be the same as when he does not use the road but instead invests and uses the second mode. The equilibrium condition is $P(q^*) - q^*C'(q^*) - C(q^*) - \bar{u} = s - rK$. The analysis only makes sense if $s > rK$. Thus, if the equilibrium condition is satisfied then so is (5), and so is the condition that government will want to impose the first-best socially optimal toll. This can be seen in Figure 1, where at q^* the curve $P(q) - qC'(q) - C(q)$ lies above $\bar{u}$ but below $s + \bar{u}$.

The result that the first-best policy can be time consistent is not obvious. For in determining the first-best toll we had to consider how the toll affects consumers' investment decisions. In contrast, when government cannot commit, it makes a decision in any period with the realisation that the toll in that period will not affect consumers' investments. Nevertheless, because consumers anticipate the tolls that will be imposed in the future, and invest accordingly, the imposition of a socially optimal toll can be credible.

Time consistency of a no-toll policy

We saw that charging the first-best socially optimal toll is a time-consistent policy. That toll, however, need not be the only time-consistent policy: under plausible conditions there can be a continuum of time-consistent policies, and in particular a zero toll can be a time-consistent policy.

Suppose the number of people who invest is $n - q_0$, the number that appears in equilibrium when consumers expect a zero toll. Now consider any period in which imposing a toll is feasible, and as before suppose current policy does not change expectations of future policy. If government reduces the number of road users below q_0, the utility of those persons induced to leave the road for the second mode is $\bar{u}$. The utility of road users declines by $P(q_0) - C(q_0) - q_0C'(q_0)$. So reducing the number of road users is not worthwhile (or a zero toll is optimal in that period) if

$$P(q_0) - C(q_0) - q_0C'(q_0) > \bar{u}. \tag{7}$$

We saw above that the equilibrium with expectations of a zero toll had

$$P(q_0) - C(q_0) = s - rK + \bar{u}. \tag{8}$$

Figure 1 shows how expressions (7) and (8) can be simultaneously satisfied: at q_0, $P(q) - qC'(q) - C(q)$ lies above $\bar{u}$, but at q_0, $P(q) - C(q)$ equals $s - rK + \bar{u}$.

Analytically, combining (7) and (8) shows that a zero toll is an equilibrium if

$$q_0 C'(q_0) < s - rK. \tag{9}$$

This inequality can be satisfied if s is sufficiently greater than rK. Data from Mohring (1999, Table 6-1, p.199) for the Minneapolis/St. Paul metropolitan area suggest that the value of $qC'(q)$ in the morning peak is about $2.03, and for the afternoon peak is about $1.40. On the other hand, if the interest rate (r) or the investment cost (K) are low, while an investment increases the benefits of using the non-congested mode by more than two dollars (as is plausible), the value of $s - rK$ can exceed two dollars. Thus, a time-consistent policy could have no toll. Government will not impose a toll because consumers' expectations and investments make it inefficient to impose one. With different expectations, however, government would impose a toll.

An obvious question is whether government can commit itself to a toll. I suspect that popularly elected officials with short terms of office will find it difficult to impose a toll that would hurt consumers. In contrast politicians who are secure in office may be willing to impose an unpopular toll, stick with it, change expectations of consumers, induce investment, and eventually reap the rewards of increased welfare. Government may also be able to commit by entering into agreements with private parties who can sue for breach of contract. Government, for example, may sell bonds with a clause that repayment is financed by road tolls, thereby inducing bond holders to pressure government to impose the tolls. Similarly, when a road is privatised, the owners gain from charging tolls. Of course, such mechanisms are not panaceas: bond holders or private operators could instead demand payment from tax revenues, and tolls designed to generate revenues are unlikely to match tolls that maximise social welfare. Nevertheless, financing methods that are in part designed to commit to tolls may ameliorate congestion problems.

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