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Revenue recycling within transport networks

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ABSTRACT

In this paper, we analyse second-best pricing and investment policy for transport networks with a revenue recycling mechanism in which the toll revenue is used for transport investments or subsidies, as in London's congestion-charging scheme. The results of this paper demonstrate that the way toll revenue is used modifies the usual results significantly, which are typically based on assuming a lump-sum transfer. First, recycling revenue as investment increases the second-best toll when the benefits from the investment exceed the costs and when demand is inelastic with respect to the toll. Recycling revenue as a subsidy has no such effect. Second, "partial" cost–benefit analysis that focuses only on the targeted transport mode would usually lead to erroneous conclusions about whether toll revenues should be used for transport investment, subsidies, or general tax revenues. Thus, "full" cost–benefit analysis, which accounts for changes in consumer and producer surpluses in all transport modes, is necessary.

1. Introduction

In many large cities throughout the world, motor transport causes severe road congestion. For instance, Transport for London (2003, p. 53) reports that the average daily speed had declined gradually before the congestion charge was introduced, and was 14.2 km per hour in central London in 2002. One of the economic solutions proposed to deal with such road congestion, at least since Vickery (1963) and Walters (1961), has been a congestion tax. However, congestion tax policies are unpopular among citizens, although recent developments in information technology make the technological barrier to introducing them much lower.

A key element of a successful congestion tax policy is its acceptability.[1] In this regard, of all the schemes so far adopted, London's congestion charge, introduced in 2003, is noteworthy. Under London's congestion-charging scheme, the revenue from the congestion charge is earmarked for improving transport in London. This clear link between the revenue from the charge and the use of the revenue might alleviate citizens' negative perceptions of congestion tax policies and make them more acceptable.

Although several authors (e.g., de Palma et al., 2007a; Goodwin, 1994 and Small, 1992) argue that the use of the congestion tax revenue is an important practical issue,[2] analyses of the earmarking of revenues for transport sectors are rare.[3] This is partly because the theoretical implication is obvious from standard public finance theory: the revenue from the congestion tax should be returned in the least distortionary way. However, one should analyse what this least distortionary way is, in various settings.

The purpose of this paper is to analyse the second-best pricing and investment policy for transport networks with a built-in mechanism for setting aside (or earmarking) the revenue derived from the pricing scheme for the purpose of investing in, or subsidizing, transport networks. In this way, the difference from the standard result, which is based on the assumption of a

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[1] For example, see de Palma et al. (2007b, p. 289): "There is now abundant evidence from various countries that acceptability is a *sine qua non* of transport policy reform."

[2] Small (1992) and Goodwin (1994) propose rules of thumb. Small (1992) suggests that one-third of the revenues should be allocated to each of the following categories: (i) monetary reimbursement to travelers as a group; (ii) substitution for general taxes; and (iii) new transportation services. Goodwin's (1994) suggestion is that one-third of the revenues should be allocated to: (i) improving the effectiveness of alternative methods of transport, especially public transport; (ii) improving the quality of roads; and (iii) general tax revenue.

[3] An exceptional study is Parry and Bento (2001). They analyze the effects of using revenue from a congestion tax to reduce income taxes or subsidize public transport, as well as to provide lump-sum transfers. However, they disregard the linking of congestion tax revenue and transport investments, as is practiced in London and elsewhere.

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lump-sum transfer, is made clear. We call this earmarking "revenue recycling" within transport networks, thus adopting terminology similar to that introduced by Bovenberg and Goulder (2002). The model in this paper is a simple stylized one and has the following features. A representative consumer demands transport services on two routes: route 1 and route 2. The two routes may be substitutes or complements. For instance, they may be roads that substitute for public transit, or they may comprise an urban highway and a complementary rural highway. For the transport authority, the price of route 2 is exogenous, possibly because route 2 is operated by another body following a principle of its own (such as self-financing or profit maximization), or perhaps because route 2 is an untolled transport mode (such as a rural road). Thus, we explicitly incorporate possible price distortion with regard to route 2. The transport authority collects revenue from route 1 and uses part of it for revenue recycling within transport networks, which we assume includes investment in route 1 and investment and a subsidy for route 2. The remaining revenue is assumed to be returned in the form of a lump-sum transfer.

The essence of this paper is the mitigation of deadweight losses. There are four sources of deadweight loss: the price on route 1, the price on route 2, the capacity on route 1, and the capacity on route 2. Provided the transport authority can control these four variables (the fares and capacities on routes 1 and 2) for the four sources of deadweight loss, the following well-known features of the first-best solution hold: (i) the fare (or the toll) equals the marginal congestion externality and (ii) the marginal benefit of the capacity equals its marginal cost. In second-best situations, in which not all the variables are controllable, the transport authority must assign one variable to control more than one source of deadweight loss. In this paper, we analyse various second-best cases and clarify the effects of an authority's inability to adopt a first-best approach to control the deadweight losses.

The structure of the paper is as follows. In Section 2, a basic model is presented. In Section 3, we deal with the case in which the revenue from route 1 is invested in route 1. In Section 4, the revenue from route 1 is invested in route 2. In Section 5, we focus on the case in which the revenue is used to provide a subsidy for route 2. In Section 6, we consider possible extensions of the model. In Section 7, numerical examples are presented. Section 8 concludes the paper.

2. The model

A representative consumer demands the composite consumer good z, a transport service on route 1, and a transport service on route 2. The transport demand on each route is x^1 and x^2. (Throughout the paper, superscripts denote routes.) We assume that both routes are congestible through their own demand, and assume that congestion increases travel time.

The utility function of a representative consumer is:

$$U = z + u(x^1, x^2), \tag{1}$$

which is assumed to be strictly concave. The quasi-linear utility function (1) implies that income effects are ignored. This simplifying assumption is justified because the share of transport expenditure in total household expenditure is usually low. The generalized budget constraint, including a time constraint is:

$$\bar{y} = z + \sum_{i=1}^{2} p^i x^i, \tag{2}$$

where the generalized price of the composite good, z, is normalized at unity and $\bar{y}$ is the maximum income. (Throughout the paper, $i, j = 1, 2$.) The generalized price per transport service on route i, p^i, is decomposed into:

$$p^i = \tau^i + c^i(x^i, K^i), \tag{3}$$

where τ^i is the "toll" on route i. For road transport, the toll can be a highway toll or a fuel tax. For railways, the toll corresponds to the "net" fare, which equals the actual fare a user pays minus the monetary operating cost; this is because the monetary operating cost is included in the generalized cost per transport service on route i, $c^i(x^i, K^i)$. We assume that $c^i(x^i, K^i)$ is higher when the volume of transport x^i is larger and when the capacity, K^i, is smaller; that is, $c^i_{x^i} > 0$ and $c^i_{K^i} < 0$.

A representative consumer maximizes his or her utility, (1), subject to the generalized budget constraint, (2). Maximization yields the following first-order conditions:

$$u_{x^i}(x^1, x^2) = p^i. \tag{4}$$

From (4), we derive the demand functions $x^1 = d^1(p^1, p^2)$ and $x^2 = d^2(p^1, p^2)$, which satisfy:

$$x^1_{p^2} = x^2_{p^1} = \frac{-u_{x^1x^2}}{|D|}, \tag{5}$$

where $|D| = u_{x^1x^1}u_{x^2x^2} - (u_{x^1x^2})^2 > 0$. Because the utility function is quasi-linear, $d^i(p^1, p^2)$ are Hicksian (compensated) demand curves, as well as Marshallian (uncompensated) demand curves. When x^1 and x^2 are substitutes (complements) with respect to the generalized prices, $x^1_{p^2} = x^2_{p^1} = \frac{-u_{x^1x^2}}{|D|} > (<)0$, which implies $u_{x^1x^2} < (>)0$.[4]

By substituting (3) for $x^1 = d^1(p^1, p^2)$ and $x^2 = d^2(p^1, p^2)$ and rearranging, we obtain $x^1 = x^1(\tau^1, \tau^2, K^1, K^2)$ and $x^2 = x^2(\tau^1, \tau^2, K^1, K^2)$. Therefore, from Eqs. (1)–(3), the total surplus, TS, can be written as:

$$\begin{aligned} TS &= U + p^1x^1 + p^2x^2 - c^1x^1 - c^2x^1 - r^1K^1 - r^2K^2 \\ &= \bar{y} - p^1x^1 - p^2x^2 + u(x^1, x^2) + p^1x^1 + p^2x^2 - c^1x^1 - c^2x^1 \\ &\quad - r^1K^1 - r^2K^2 \\ &= \bar{y} + u(x^1(\tau^1, \tau^2, K^1, K^2), x^2(\tau^1, \tau^2, K^1, K^2)) \\ &\quad - c^1(x^1(\tau^1, \tau^2, K^1, K^2), K^1)x^1(\tau^1, \tau^2, K^1, K^2) \\ &\quad - c^2(x^2(\tau^1, \tau^2, K^1, K^2), K^2)x^2(\tau^1, \tau^2, K^1, K^2) - r^1K^1 - r^2K^2, \end{aligned} \tag{6}$$

where r^i is the unit rental price of the capacity on each route.

Maximizing (6) with respect to τ^1, τ^2, K^1, and K^2 yields the following first-best results:

$$\tau^i = c^i_{x^i}x^i, \quad \text{and} \tag{7}$$

$$-c^i_{K^i}x^i = r^i. \tag{8}$$

Eq. (7) shows that the fare on each route equals the marginal congestion externality. Eq. (8) shows that the marginal benefit of capacity, which stems from reduced congestion, equals its marginal cost.

From Section 3 onward, we focus on more realistic second-best situations, where at least the fare on route 2 is assumed fixed, because tolls cannot be fine-tuned on all transport routes in reality. 100a% of the revenue from the fare (which can be tolls or taxes) on route 1 is assumed to be used within transport networks as investments or subsidies, and the remaining 100(1 − a)% of the revenue is assumed to be returned in the form of a lump-sum transfer, where a ($0 \leqslant a \leqslant 1$) is a parameter that shows the degree of revenue recycling within transport networks. It is useful to summarize the cases to be analysed in Table 1, delineating control variables, which the transport authority can change, and exogenous variables. We do not analyse the trivial case in which the revenue from route 1 is used to subsidize route 1.

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[4] This definition of substitutes is based on Hicks (1975).