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# Cost-benefit rules for transport projects when labor supply is endogenous and taxes are distortionary\*

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## Abstract

We embed a stylized traffic model within a general equilibrium model in which labor supply is endogenous and income taxes are distortionary. Within this framework we derive simple rules for performing a cost-benefit analysis that can be applied knowing only the output of the traffic model and a factor that accounts for the labor market distortion in a consistent manner. Thus the rules that we derive should be applicable in the large number of cost-benefit analyses that are performed based on the output of traffic models. Such analyses are routinely performed and guide the allocation of a large share of public investment in many countries of the world as well as the assessment of policies such as road user charging. We find that the rules for leisure transport are exactly the same as in a conventional CBA that includes the marginal cost of public funds. For business travel and commuting we find new rules as a result of the assumption that transport costs have the same distortionary effect as income taxes.

KEYWORDS: Cost-benefit; Transport; General Equilibrium

JEL codes:

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# 1 Introduction

Welfare economic evaluations of projects or policies in the transport sector often proceed by first running a traffic model to predict the consequences for traffic demand and transport costs and next by performing a cost-benefit analysis (CBA). Traffic models are often large and complicated things, comprising networks with thousands of links and nodes. The CBA is based on a simple theoretical economic model, such that the traffic model is, in a sense, embedded in the economic model. The point of this paper is to extend this framework to take into account tax distortion on the labor market and then derive consistent CBA rules that can be applied to the output of a traffic model.

The traffic project may affect the level of general taxation, either because there is an investment to be financed or because the project otherwise has an impact on government revenues. The level of taxation affects the labor supply and creates a distortion of the labor market. This distortion is likely to be significant relative to the outcome of a CBA. This motivates the inclusion of the marginal cost of public funds in the analysis.

The wedge between the gross and the net wage comprises not only income taxes but also the costs of commuting. Furthermore, the transport costs to firms has an impact on labor productivity and hence on employment and wages. Hence, transport costs are tightly connected to the marginal cost of public funds. So when we consider the distortionary effect on the labor market of financing the traffic project via taxes we must also consider the distortionary effect of the project itself.

In this paper we formulate a consistent theoretical framework in which a traffic model is embedded within a stylized general equilibrium model. The general equilibrium model incorporates endogenous labor supply and hence accounts for the distortionary effect of taxation on the labor market. From this framework we derive simple rules that can be applied in CBAs using the output of a traffic model. These rules apply not only to investment projects that increase the capacity of links in the traffic network but also to projects such as road user charging. We have not been able to find such rules in the literature and therefore see a clear demand for the present

analysis.

We are concerned with evaluating transport policies and not with the general tax system. Thus we are content to consider just one generic tax instrument, an income tax, to balance the government budget. We define the marginal cost of public funds relative to this instrument. In this we follow the arguments of Sandmo (1998) that when the MCPF is to be used as a practical tool to policymakers for different projects, then the definition of the MCPF must not be project specific. Hence, the potential tax revenue effects of the public spending must be kept out of the definition of the MCPF and instead be incorporated on the benefit side in the CBA.

The general equilibrium model presented in this paper does not comprise other labor market imperfections besides the tax wedge. This simplification allows us to obtain simple cost-benefit rules. Research exists to show that other labor market imperfections may be quite important. Thus, Venables (2007) shows that agglomeration effects may be quite significant, while Pilegaard and Fosgerau (2008) similarly shows that the effects of search unemployment may be large relative to the outcome of a CBA.

The structure of the paper is as follows. In section 2 we first formulate a stylized traffic model and specify the endogenous variables of that model. We then proceed to formulate a general equilibrium model comprising a representative leisure traveler, a representative commuter with endogenous labor supply, a representative firm and a government. In section 3 we then analyze a range of policies. We first analyze the effect of a marginal change in government spending financed through a distortionary income tax. This gives us the marginal cost of public funds (MCPF). Then we consider marginal changes in travel times for leisure travelers, commuters and firms and compute the welfare effects using the MCPF. Next, we analyze the welfare effects of a marginal change in the resource travel costs for commuters, leisure travelers and firms. The model allows for taxes on transport such that an analysis of the welfare effects of, e.g., road pricing or fuel taxes is accommodated. Again we analyze the welfare effects of marginal changes to transport taxes for commuters, leisure travelers and firms. We conclude this section by summarizing the CBA rules that we derive. Section 4 discusses the interpretation of the present theoretical

model in an application and we extend the rules to the situation with non-marginal changes. Section 5 concludes.

## 2 Theoretical framework

### 2.1 The traffic model

The basis of the type of CBAs that we consider is a traffic model. In this section we describe a stylized traffic model that is then embedded in a general equilibrium model.

A basic component of a traffic model is a description of the traffic network. This comprises, e.g., the road network including costs and travel times on each link as a function of traffic volumes and/or a public transport network including fares, travel times and timetables. The costs to travelers can be divided into resource costs and taxes and charges. Another basic component is an origin-destination matrix, giving information about the number of trips from all origins to all destinations in the area under consideration. The origin-destination matrix comprises different types of trips, we consider leisure travel, commuting and business travel. The volume of leisure travel may be determined endogenously within the traffic model. We take the volume of commuting and business travel to be given exogenously from the perspective of the traffic model such that the traffic model does not tell us the level of employment and the activity of firms. The traffic model is allowed to shift commuting and business travel between modes and routes.

The traffic model then predicts how trips are executed in the traffic network. It thus predicts for each trip the choice of transport mode and further the route choice. This information is then collected to a prediction of traffic loads on the links of the traffic network. Furthermore, the traffic model computes travel times and costs for each trip, where the travel costs for each trip are divided into resource costs and taxes and charges.

Formally, let  $s$  be a state variable that summarizes the exogenous information about the traffic network. Then the traffic model delivers the travel time  $t(s)$  for a specific trip as a function of the state variable, it further

delivers the use of resources  $m(s)$  such as petrol and vehicles and the tax and charge payment  $\rho(s)$  related to a trip.

The number of trips  $H$  in a specific origin-destination relation may in some cases be given exogenously. We take this to be the case for commuting travel and freight/business travel. This is necessary for consistency with the general equilibrium model to be formulated in the following because the labor supply will be endogenous in the general equilibrium model. For leisure travel we leave open the possibility that the number of trips may be endogenous to the traffic model.

## 2.2 Two representative consumers

We now turn to the formulation of the general equilibrium model. We begin by describing two representative consumers. We normalize the number of consumers of each type to 1. One is a leisure traveler, he travels for activities out of home and does not work. The other is a commuter, he chooses his level of employment and pays income tax. Thus we ignore substitution between travel for different purposes and we suggest the resulting error is likely to be small.<sup>1</sup> We use superscripts  $n$  (for not working) to denote that variables relate to the representative leisure traveler. Superscripts  $c$  indicate variables that relate to the representative commuter.

### 2.2.1 The leisure traveler

Our leisure traveler derives utility  $U^n(H_t^n, C^n, H_o^n)$  from leisure  $H_t^n$  at home, consumption  $C^n$  and time spent out of home  $H_o^n$ . Time spent out of home requires travel taking time. We may interpret the consumer as an average over many travelers, each consumer carries out an activity of fixed duration, such that the travel time is proportional to the time spent out of home,  $t^n H_o^n$ .

All his income is spent on consumption and on transport. The price level of consumption is  $(1 + v)p$ , where  $v$  is a value-added tax and  $p$  is the factor price level. The transport costs cover the cost of a transport good,

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<sup>1</sup>It is only so-called activity-based traffic models that include substitution between travel purposes (Ben-Akiva et al., 1996; Fosgerau, 2001).

which we interpret as comprising resources such as petrol and vehicles, as well as transport taxes. Denoting the use of the transport good per leisure trip by  $m^n$  we fix units such that the factor price  $p$  of the transport good is the same as the factor price of consumption. Then the resource cost of leisure travel is  $pm^n H_o^n$  in factor prices. We allow for a tax on leisure travel with revenue  $\rho^n H_o^n$ . This tax includes all taxes and charges such as petrol duties, annual charges, vehicle registration taxes as well as road pricing and value added tax.

As the leisure traveler does not work his only income is a lump sum transfer from the government of  $\tau^n$ . His money budget thus becomes

$$(1 + v)pC^n + pm^n H_o^n + \rho^n H_o^n = \tau^n. \quad (1)$$

His total time available  $\bar{H}^n$  is spent on leisure and travel such that his time budget becomes

$$\bar{H}^n = H_l^n + H_o^n + t^n H_o^n. \quad (2)$$

The leisure traveler maximizes utility by choosing  $H_l^n$ ,  $C^n$  and  $H_o^n$ . Taking everything else as given, the lagrangian becomes

$$\begin{aligned} \lambda(H_l^n, C^n, H_o^n) = & U^n(H_l^n, C^n, H_o^n) \\ & + \mu_I^n (\tau^n - (1 + v)pC^n - \rho^n H_o^n - pm^n H_o^n) \\ & + \mu_T^n (\bar{H}^n - H_l^n - H_o^n - t^n H_o^n), \end{aligned}$$

The first-order conditions for this problem are

$$U_{H_l}^n = \mu_T^n \quad (3)$$

$$U_C^n = \mu_I^n (1 + v)p \quad (4)$$

$$U_{H_o}^n = \mu_I^n (\rho^n + pm^n) + \mu_T^n (1 + t^n) \quad (5)$$

where  $\mu_I^n$  is the marginal utility of income and  $\mu_T^n$  is the marginal utility of time. We note that the leisure traveler's marginal value of time is

$$V^n = \frac{\mu_T^n}{\mu_I^n} = \frac{(1 + v)p U_{H_l}^n}{U_C^n}.$$

### 2.2.2 The commuter

The representative commuter derives utility  $U^c(H_l^c, C^c)$  from leisure  $H_l^c$  and consumption  $C^c$ .<sup>2</sup> We may again interpret him as an average over many potential commuters. When working, they work a fixed number of hours per working day and they commute once per working day, such that the time spent commuting is proportional to the average hours worked. So any change in employment takes place on the extensive margin, deciding on how many days to work.<sup>3</sup> The model does not allow workers to decide how many hours to work on a working day.<sup>4</sup> The representative commuter then works  $H_w^c$  hours and commuting takes a total of  $t^c H_w^c$  hours.

Like the leisure traveler, all the commuter's income is spent on consumption and on transport. The resource cost of commuting is  $pm^c H_w^c$  in factor prices and the tax on commuting has the revenue  $\rho^c H_w^c$ .

The commuter receives a gross hourly wage of  $w$  out of which he pays income taxes at the rate of  $\sigma$ . He further receives a lump sum transfer from the government of  $\tau^c$ . Altogether his money budget constraint becomes

$$(1 + v)pC^c + \rho^c H_w^c + pm^c H_w^c = w(1 - \sigma)H_w^c + \tau^c \quad (6)$$

His total time available  $\bar{H}^c$  is spent on leisure, work and commuting, which takes  $t^c$  hours per trip. Thus his time budget becomes

$$\bar{H}^c = H_w^c + H_l^c + t^c H_w^c \quad (7)$$

The commuter maximizes utility by choosing  $H_w^c$ ,  $C^c$  and  $H_l^c$  taking everything else as given. The lagrangian becomes

$$\begin{aligned} \Lambda(H_w^c, H_l^c, C^c) = & U^c(H_l^c, C^c) \\ & + \mu_I^c (w(1 - \sigma)H_w^c + \tau^c - (1 + v)pC^c - \rho^c H_w^c - pm^c H_w^c) \\ & + \mu_T^c (\bar{H}^c - H_w^c - H_l^c - t^c H_w^c), \end{aligned} \quad (8)$$

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<sup>2</sup>So he does not derive utility or disutility from working time or commuting time (DeSerpa, 1971).

<sup>3</sup>We base this on recent studies like, e.g., Kleven and Kreiner (2006) and the references therein that find that the extensive responses for the labor force (participation) are more important than the intensive responses (hours of work).

<sup>4</sup>This assumption was also used in, e.g., Parry and Bento (2001).



where  $\mu_I^c$  is the marginal utility of income and  $\mu_T^c$  is the marginal utility of time. The first-order conditions for this problem are

$$\mu_I^c(w(1 - \sigma) - \rho^c - pm^c) = \mu_T^c(1 + t^c) \quad (9)$$

$$U_{H_t}^c = \mu_T^c \quad (10)$$

$$U_C^c = \mu_I^c(1 + v)p \quad (11)$$

We note that the value of leisure time in the model is

$$V^c = \mu_T^c / \mu_I^c = \frac{w(1 - \sigma) - \rho^c - pm^c}{1 + t^c},$$

i.e. the net wage rate after allowing for commuting time and cost. The net wage of the commuter is  $\bar{w} = w(1 - \sigma) - \rho^c - pm^c$ . We shall denote the sensitivity of his labor supply with respect to the net wage by  $\epsilon = \frac{\partial H_w^c}{\partial \bar{w}}$ . Since the net wage is determined by a number of factors, we can express the sensitivity of the labor supply with respect these variables in terms of  $\epsilon$ .

$$\frac{\partial H_w^c}{\partial \sigma} = -w\epsilon, \quad \frac{\partial H_w^c}{\partial w} = (1 - \sigma)\epsilon, \quad \frac{\partial H_w^c}{\partial \rho^c} = -\epsilon, \quad \frac{\partial H_w^c}{\partial m^c} = -p\epsilon, \quad \frac{\partial H_w^c}{\partial t^c} = -\epsilon V^c. \quad (12)$$

These relationships will be useful in the following.

### 2.3 A representative firm

We assume a representative firm producing under conditions of perfect competition with constant returns to scale, and labor and the transport good as the only inputs. For simplicity we formulate the use of the transport good such that the firm buys this on the market and such that production depends only on the input of labor.<sup>5</sup> Output then equals a constant productivity times labor. Labor productivity in turn depends on the input of transport, such that output becomes  $Y = (\alpha - \beta t^f)H_w^c$ . The interpretation

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<sup>5</sup>We could just as well make the interpretation that the transport resource is imported while trade balance is enforced.

here is that part of the labor input is spent on transport, which can be business travel or transport of goods.

The firm pays transport taxes of  $\rho^f H_w^c$  and buys the transport good for  $pm^f H_w^c$ . Perfect competition yields the zero profit condition

$$pY = wH_w^c + \rho^f H_w^c + pm^f H_w^c. \quad (13)$$

This equation shows that the hourly wage is fixed at  $w = p(\alpha - \beta t^f) - \rho^f - pm^f$ .

It is convenient to consider the market clearing conditions at this place. The output is used solely for private consumption  $C = C^c + C^n$ , public consumption  $G$  and resources for transport  $M = m^c H_w^c + m^n H_o^n + m^f H_w^c$  and we write

$$C + G + M = Y = (\alpha - \beta t^f) H_w^c. \quad (14)$$

## 2.4 The government

The government receives the value added tax, the income tax and transport taxes and spends on public consumption  $G$ . The budget is balanced by the lump sum transfers.

$$vpC + \sigma wH_w^c + \rho^c H_w^c + \rho^n H_o^n + \rho^f H_w^c = pG + \tau^c + \tau^n. \quad (15)$$

The final item needed to close the model is to fix the price level  $p$ .

It is convenient to add the government balance to the zero profit condition for the firm to obtain

$$(1 + v)pG + \tau^c + \tau^n = T^c H_w^c + (\rho^n - vpm^n) H_o^n \quad (16)$$

where

$$T^c = (v + \sigma)w + \rho^c + (1 + v)\rho^f - vpm^c \quad (17)$$

is the tax revenue in market prices per unit of labor supplied.

## 3 Policies

In the analysis of policies we will formulate rules that can be applied to the output of traffic models, i.e. to changes in traffic levels and in travel times

and costs. We will assume that the government budget is always balanced by changing the income tax rate. This is the most relevant change to consider since non-distorting tax changes are generally not available outside the world of the model. Furthermore, the rules are intended to be applied to the analysis of transport projects, where the general tax policy is not an issue to be considered. So we use the income tax in the model to represent a generic distortionary tax that is used to balance the government budget under all transport policies considered (Sandmo, 1998).

We proceed in two steps. First, in the next section, we compute the welfare effect of a change in the income tax, where the use of the change in tax revenues has no effect on welfare. This exercise provides us with the marginal cost of public funds (MCPF).

The subsequent sections then analyze a range of policies by first computing the direct welfare effects using government spending to balance the budget and second by using the MCPF to find the full effects. For the analysis we assume that we have available the outputs from a traffic model as well as an estimate of the MCPF.

### 3.1 Government spending

We begin by considering a marginal increase in government spending  $dG$  without any direct effect on utilities. This policy could represent spending on infrastructure, considered separately from the resulting improvements. Since the increase in spending is financed by the income tax  $\sigma$  we only need to consider the effect on the utility of the commuter.

The change in consumer utility in monetary terms is as follows, using the first-order conditions for utility maximization.

$$\begin{aligned} \frac{dU^c}{\mu_I^c} &= \frac{U_{H_t}^c}{\mu_I^c} dH_t^c + \frac{U_C^c}{\mu_I^c} dC^c \\ &= V^c dH_t^c + (1 + v) p dC^c. \end{aligned} \tag{18}$$

Combine first with the commuter's time budget in (7) to find that

$$\frac{dU^c}{\mu_I^c} = -(w(1 - \sigma) - \rho^c - pm^c) dH_w^c + (1 + v) p dC^c$$

and next with the commuter's monetary budget in (6) such that

$$\frac{dU^c}{\mu_1^c} = -wH_w^c d\sigma \quad (19)$$

That is, the loss to the commuter is equal to the change in income tax payment. It is possible to compute the corresponding change in government spending. Use the balance in (16) to find

$$\begin{aligned} (1 + \nu)pdG &= H_w^c \frac{\partial T^c}{\partial \sigma} d\sigma + T^c \frac{\partial H_w^c}{\partial \sigma} d\sigma \\ &= wH_w^c d\sigma - w\epsilon T^c d\sigma \end{aligned}$$

Insert this twice into (19) to see that

$$\begin{aligned} \frac{dU^c}{\mu_1^c} &= -(1 + \nu)pdG - w\epsilon T^c d\sigma \\ &= -\left(1 + \frac{\epsilon T^c}{H_w^c - \epsilon T^c}\right)(1 + \nu)pdG \\ &= -\frac{H_w^c}{H_w^c - \epsilon T^c}(1 + \nu)pdG \end{aligned}$$

Thus to find the welfare loss of an increase in public spending of  $dG$  financed by an increase in the income tax  $\sigma$  we need to multiply the spending change by  $1 + \nu$  to convert to market prices and next to multiply by the marginal cost of public funds (in market prices) of  $\frac{H_w^c}{H_w^c - \epsilon T^c}$  to account for the labor market distortion. Defining  $1 + \lambda = \frac{H_w^c}{H_w^c - \epsilon T^c}$  we say that  $\lambda = \frac{\epsilon T^c}{H_w^c - \epsilon T^c}$  is the distortionary loss of taxation. We assume this parameter is known.<sup>6</sup> We note that taxes on commuting and business travel contribute to the distortion as part of  $T^c$ .

## 3.2 Transport improvements - time use

### 3.2.1 Leisure travelers

We turn now to the case where the leisure travel time  $t^n$  is changed marginally by  $dt^n$  and inspect the welfare consequences. We initially bal-

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<sup>6</sup>It is available for standardized cost-benefit analyses at least in Denmark (Trafikministeriet, 2003), Sweden (SIKA, 2000) and the US (of Management and Budget, 1992).

ance the budget through  $G$  at no consequence for welfare. The leisure traveler experiences a welfare gain of

$$\frac{dU^n}{\mu_1^n} = -V^n H_o^n dt^n.$$

This is immediately recognizable as the leisure travelers value of time times the number of leisure travelers times the negative of the change in travel time.

The resulting change in leisure travel has effects on the government balance, which must also be accounted for. We compute the effect on the government balance by using (16) and the change in the government balance is simply

$$(1 + v)p\partial G = (\rho^n - vpm^n) dH_o^n.$$

i.e. the change in revenue as a consequence of a changed leisure travel behaviour. Now the change in government balance is to be financed through the income tax. Applying the MCPF we find that the total effect on welfare is

$$-V^n H_o^n dt^n + (1 + \lambda) (\rho^n - vpm^n) dH_o^n.$$

This result is identical to the conventional analysis. We note that the change in leisure travel  $dH_o^n$  is available from the traffic model.

### 3.2.2 Commuters

We consider now the case where the commuting travel time  $t^c$  is changed marginally by  $dt^c$  and inspect the welfare consequences. We initially balance the budget through  $G$  at no consequence for welfare. Combine again (18) with the time and money budgets to find that

$$\frac{dU^c}{\mu_1^c} = -V^c H_w^c dt^c$$

Again, this is immediately recognisable as the commuter value of time times the number of commuters times the negative of the change in commuting time. Use (16) to find that

$$(1 + v)p\partial G = T^c dH_w^c,$$

such that the change in the government balance is a function of the employment change resulting from the policy.<sup>7</sup> Applying the MCPF we find that the total effect on welfare is

$$-V^c H_w^c dt^c + (1 + \lambda) T^c dH_w^c$$

We have assumed that the change in employment resulting from the change in commuting time is not available from the traffic model. However, we may use that  $\frac{\partial H_w^c}{\partial t^c} = -\epsilon V^c$  (from (12)) to find the total welfare effect as

$$-(1 + \lambda) V^c H_w^c dt^c.$$

Here the term  $1 + \lambda$  yields an additional benefit from commuting time reductions compared to the conventional analysis. The additional benefit arises from increased employment leading to increased income tax payments.

### 3.2.3 Firms

We then consider a change to the travel time for firms of  $dt^f$ . We find that the commuter experiences a wage change of  $-p\beta dt^f$  and hence a utility change of

$$-(1 - \sigma)p\beta H_w^c dt^f.$$

The effect on the government balance is

$$(1 + \nu)p dG = T^c dH_w^c - (\nu + \sigma)p\beta H_w^c dt^f$$

such that the welfare effect becomes

$$-(1 - \sigma)p\beta H_w^c dt^f + (1 + \lambda)(T^c dH_w^c - (\nu + \sigma)p\beta H_w^c dt^f).$$

Assuming still that the employment change resulting from the policy is not available from the traffic model we may use that

$$dH_w^c = \frac{\partial H_w^c}{\partial t^f} dt^f = \frac{\partial H_w^c}{\partial w} \frac{\partial w}{\partial t^f} dt^f = -(1 - \sigma)\epsilon p\beta dt^f$$

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<sup>7</sup>Remember that our model only includes labor market effects from the extensive margin, so there is no effect resulting from a changed number of work-hours.

such that the welfare effect becomes

$$-(1 - \sigma)p\beta H_w^c dt^f - (1 + \lambda)((1 - \sigma)\epsilon p\beta T^c + (\nu + \sigma)p\beta H_w^c) dt^f \quad (20)$$

$$= -(1 + \lambda)(1 + \nu)p\beta H_w^c dt^f. \quad (21)$$

In this case the net effect is the change in transport costs for the firm of  $p\beta H_w^c dt^f$ , converted to market prices by  $1 + \nu$  and multiplied by the MCPF factor  $1 + \lambda$ . This result parallels the result for commuters; we will return to this issue later.

### 3.3 Transport improvements - resources

In this section we consider the second policy where the resource costs of transport are changed. This corresponds, e.g., to the situation where an existing road is replaced by a new road of different length. Like before we consider commuters, leisure travelers and firms in turn. Also like before, we first compute the direct welfare effect of the changes and then use the effect on the government balance to find the welfare effect of compensation through the income tax.

#### 3.3.1 Leisure travelers

Now we consider a change in leisure transport resource costs. We find the direct welfare effect to be

$$\frac{dU^n}{\mu_1^n} = -H_0^n p dm^n.$$

The effect on the government balance is

$$(1 + \nu) p dG = (\rho^n - \nu p m^n) dH_0^n - H_0^n \nu p dm^n$$

and the effect on total welfare after compensation through the income tax is therefore

$$-H_0^n p dm^n + (1 + \lambda) [(\rho^n - \nu p m^n) dH_0^n - H_0^n \nu p dm^n].$$

### 3.3.2 Commuters

First we find that the direct welfare effect of changing the resource costs of commuting transport is

$$\frac{dU^c}{\mu_1^c} = -pH_w^c dm^c.$$

The effect on the government balance is

$$\begin{aligned} (1 + \nu)pdG &= T^c dH_w^c + H_w^c dT^c \\ &= T^c dH_w^c - \nu p H_w^c dm^c \end{aligned}$$

such that the welfare effect after compensation through the income tax is

$$-pH_w^c dm^c + (1 + \lambda) [T^c dH_w^c - \nu p H_w^c dm^c]$$

We now use that  $dH_w^c = \frac{\partial H_w^c}{\partial m^c} dm^c = -p\varepsilon dm^c$  and find the welfare effect to be

$$\begin{aligned} &-H_w^c p dm^c + (1 + \lambda) [-\varepsilon T^c p dm^c - H_w^c \nu p dm^c] \\ &= -(1 + \lambda)(1 + \nu)H_w^c p dm^c \end{aligned}$$

Thus the total welfare effect of a change in the resource cost of commuting is first the direct cost of the resource  $H_w^c p dm^c$  converted to market prices with  $1 + \nu$  and multiplied by  $1 + \lambda$  to account for the distortionary effect through the labor market.

### 3.3.3 Firms

We then consider the effect of changing the resource costs of firms' transport. From the wage equation we see that the commuters experience a wage change of  $-p dm^f$  leading to a utility change of

$$\begin{aligned} \frac{dU^c}{\mu_1^c} &= (1 - \sigma) H_w^c dw \\ &= -(1 - \sigma) H_w^c p dm^f \end{aligned}$$



The government balance and the zero profit condition gives us

$$\begin{aligned}
(1 + \nu) p dG &= T^c dH_w^c + H_w^c dT^c \\
&= T^c dH_w^c + (\nu + \sigma) H_w^c dw \\
&= T^c dH_w^c - (\nu + \sigma) H_w^c p dm^f.
\end{aligned}$$

The total welfare effect after compensation through the income tax is therefore given by

$$-(1 - \sigma) H_w^c p dm^f + (1 + \lambda) [T^c dH_w^c - (\nu + \sigma) H_w^c p dm^f].$$

We now use that  $dH_w^c = \frac{\partial H_w^c}{\partial m^f} dm^f = \frac{\partial H_w^c}{\partial w} \frac{\partial w}{\partial m^f} dm^f = -(1 - \sigma) \varepsilon p dm^f$  and rewrite the expression to

$$\begin{aligned}
&-(1 - \sigma) H_w^c p dm^f + (1 + \lambda) [-(1 - \sigma) \varepsilon T^c p dm^f - (\nu + \sigma) H_w^c p dm^f] \\
&= -(1 + \lambda) (1 + \nu) H_w^c p dm^f.
\end{aligned}$$

So again we find the welfare effect to be the direct cost effect of  $H_w^c p dm^f$  converted to market prices with  $1 + \nu$  and multiplied by  $1 + \lambda$  to account for the labor market distortion.

## 3.4 Taxes on transport

In this section we consider changes in the three forms of transport taxes present in the model. Like before we consider commuters, leisure travelers and firms in turn. We first compute the direct welfare effect of the changes and then use the effect on the government balance to find the welfare effect of compensation through the income tax.

### 3.4.1 Leisure travelers

Consider now a change in the transport tax for leisure travelers. We find that the direct effect when G absorbs the effect on the government balance is just

$$\frac{dU^n}{\mu_1^n} = -H_o^n d\rho^n. \quad (22)$$

The effect on the government balance is

$$(1 + v)pdG = H_0^n d\rho^n + (\rho^n - vpm^n) dH_0^n$$

such that the total effect on welfare after compensation through the income tax is

$$\begin{aligned} & - H_0^n d\rho^n + (1 + \lambda) [H_0^n d\rho^n + (\rho^n - vpm^n) dH_0^n] \\ & = \lambda H_0^n d\rho^n + (1 + \lambda)(\rho^n - vpm^n) dH_0^n. \end{aligned}$$

Note again that  $dH_0^n$  and  $d\rho^n$  are outputs from the traffic model. The result indicates two effects on welfare of increasing the transport tax for leisure travelers. The first effect is the increase in revenues which may be used to lower the income tax and reduce the distortion on the labor market. The second effect is that leisure travel will be reduced, which leads to a decrease in tax revenues. Thus the sign of the overall effect is ambiguous. The welfare effect of increasing the leisure travel tax is positive when the tax is small but becomes negative at some point where the tax exceeds the VAT on the transport good. Thus the optimal tax on a leisure trip exceeds the VAT of the resource cost of the trip and the difference between the optimal tax and the VAT is large if the price elasticity of the demand for leisure trips is small.

### 3.4.2 Commuters

From the commuter's utility maximization problem we find that the direct welfare effect of changing the tax on commuting by  $d\rho^c$  is

$$\frac{dU^c}{\mu_1^c} = -H_w^c d\rho^c \quad (23)$$

The effect on the government balance is

$$\begin{aligned} (1 + v)pdG & = T^c dH_w^c + H_w^c dT^c \\ & = T^c dH_w^c + H_w^c d\rho^c \end{aligned}$$

such that the total welfare effect after compensation through the income tax is

$$-H_w^c \lambda d\rho^c + (1 + \lambda) T^c dH_w^c.$$

The welfare effect clearly reduces to zero in the case when  $\lambda = 0$  and  $dH_w^c = 0$ . This is also true in the general case. Using that  $\frac{\partial H_w^c}{\partial \rho^c} = -\epsilon$  we find the welfare effect to be

$$-H_w^c \lambda d\rho^c + (1 + \lambda) \epsilon T^c d\rho^c = 0.$$

This result is unsurprising given our assumption that labor supply is only affected at the extensive margin such that the income tax and the commuting transport tax act in the same way on commuters.

The result is also in line with the double-dividend literature (e.g. Goulder, 1995), where most studies find that when assuming no involuntary unemployment a double dividend is not feasible since the distortionary costs of introducing a new pollution tax equal or exceed the gains or reducing the existing distortionary taxes. The reason is that the tax burden cannot be shifted away from the employed workers. If it is possible to shift the tax burden away from employed workers to other groups of consumers there is a possibility of a double-dividend. In our model we have no environmental externality but it could easily be included and we would expectedly get the same result with respect to double dividend.

### 3.4.3 Firms

We consider now an increase in the transport tax on firms  $\rho^f$ . In this situation there is the special complication that the change in the cost to firms of transport changes the wage. The leisure traveler is not affected by this policy.

Find from the commuter's utility maximization problem that  $\frac{dU^c}{\mu_1^c} = (1 - \sigma)H_w^c dw$ . From the wage equation find that  $dw = -d\rho^f$ . Then use zero profit and the government balance to find that

$$\begin{aligned} (1 + v)pdG &= T^c dH_w^c + H_w^c dT^c \\ &= T^c dH_w^c + (1 - \sigma)H_w^c d\rho^f \end{aligned}$$

such that the total welfare effect after compensation through the income tax becomes

$$-(1 - \sigma)H_w^c d\rho^f + (1 + \lambda) [T^c dH_w^c + (1 - \sigma)H_w^c d\rho^f].$$

We may use  $dH_w^c = \frac{\partial H_w^c}{\partial \rho^f} d\rho^f = \frac{\partial H_w^c}{\partial w} \frac{\partial w}{\partial \rho^f} d\rho^f = -(1 - \sigma)\epsilon d\rho^f$  to find the employment change such that the total welfare effect becomes

$$-(1 - \sigma)H_w^c d\rho^f + (1 + \lambda)(1 - \sigma) [H_w^c - T^c \epsilon] d\rho^f = 0.$$

This result is unsurprising since we are considering a tax that affects the wage which is compensated through the income tax. Note that the result depends on the assumption that the volume of firms' transport is linked directly to the level of employment, such that there is no possibility for substituting firms' transport with another input.

## 3.5 Summary of policies

### 3.5.1 Marginal changes

We conclude this section with a brief summary of the welfare effects of the policies that we have analyzed. We consider a simultaneous change in travel time, transport tax and resource use and note that we may just add the effects since we are considering marginal changes.

The total welfare effect for leisure travelers is the most complicated.

$$-V^n H_o^n dt^n + \lambda H_o^n d\rho^n - (1 + v + \lambda v) H_o^n p dm^n + (1 + \lambda)(\rho^n - v p m^n) dH_o^n$$

There is first the change in time consumption; second, the change in transport taxes only has a net effect through the labor market distortion; third, the change in resource use has a direct effect in market prices as well as an effect due to the change in distortion associated with the change in government revenues. Finally, the change in the number of leisure travelers has an effect on the government balance.

In comparison the total welfare effect for commuters is more simple and it is quite intuitive. We have found the total welfare effect to be

$$-(1 + \lambda)H_w^c [V^c dt^c + (1 + v)p dm^c].$$

This is intuitively interpretable as the change in generalized travel costs net of taxes other than VAT and multiplied by the number of commuters and multiplied by  $1 + \lambda$  to take account of the labor market distortion.

The total welfare effect for firms' travel is comparable to the effect for commuters.

$$-(1 + \lambda)(1 + \nu)H_w^c(p\beta dt^f + pdm^f)$$

This is just the change in total transport costs for the firm, net of transport taxes, converted to market prices and multiplied by the MCPF to take account of the labor market distortion.

Note that the effects for firms and commuters are equal. This can be seen, as the last term for the firms ( $p\beta dt^f + pdm^f$ ) is defined in factor prices while the multiplication with  $(1 + \nu)$  converts it to market prices. The term  $p\beta$  is the value of time in factor prices for the firms and thus  $(1 + \nu)p\beta$  is the value of time for firms in market prices. The corresponding last term for the commuters,  $(V^c dt^c + (1 + \nu) pdm^c)$  is already defined in market prices as the value of time by definition is in market prices, while the factor cost is multiplied with  $(1 + \nu)$ .

### 3.5.2 Non-marginal changes

At this point we will consider the application of these rules to non-marginal changes. We consider a change in the state of the world from  $s_0$  to  $s_1$ . The traffic model provides us with  $t^c(s)$ ,  $m^c(s)$ ,  $\rho^c(s)$ ,  $H_w^c$ ,  $t^n(s)$ ,  $m^n(s)$ ,  $\rho^n(s)$ ,  $H_o^n(s)$ ,  $t^f(s)$ ,  $m^f(s)$  and  $\rho^f(s)$ . We proceed by integrating the expressions for the welfare effects from  $s_0$  to  $s_1$ . As is standard in CBA we interpolate all relevant functions linearly between the endpoints such that the familiar rule-of-a-half obtains.

As an example we show the integration for tax changes for leisure travel holding the other travel costs constant. We use the notation  $\Delta f = f(s_1) - f(s_0)$  and  $\bar{f} = (f(s_0) + f(s_1))/2$ .

$$\begin{aligned} & \int_{s_0}^{s_1} \left[ \lambda H_o^n(s) \left( \frac{d\rho^n(s)}{ds} \right) + (1 + \lambda)(\rho^n(s) - \nu pm^n) \frac{dH_o^n(s)}{ds} \right] ds \\ & \approx \lambda \bar{H}_o^n \Delta \rho^n + (1 + \lambda)(\bar{\rho}^n - \nu pm^n) \Delta H_o^n \\ & = -\bar{H}_o^n \Delta \rho^n + (1 + \lambda) \Delta(H_o^n \rho^n) - (1 + \lambda) \nu pm^n \Delta H_o^n \end{aligned}$$

We note that this expression is completely standard, corresponding to the

change in surplus for travelers, the direct effect on revenues and the indirect effect on revenues due to the change on leisure travel.

In the derivation of the rules in the paper we have maintained that the aggregate labor supply and the aggregate business travel demand is constant in the traffic model and we have only considered one route. However, a traffic model usually covers a network with several mode and route options for a given origin-destination combination. Therefore, the number of commuting trips or firms' trips on a specific route is not necessarily constant in the traffic model. When we compute the formulas for non-marginal changes for commuting and business travel we must therefore take into account that the number of commuting and business trips on any route may change.

The rules for the welfare effects of non-marginal changes for a single mode and route can now be summarized as follows.

For leisure travelers we find

$$\begin{aligned} & -\overline{H}_0^n(V^n\Delta t^n + \Delta\rho^n + p\Delta m^n) \\ & + (1 + \lambda)\overline{H}_0^n(\Delta\rho^n - vp\Delta m^n) \\ & + (1 + \lambda)(\overline{\rho}^n - \overline{vpm}^n)\Delta H_0^n. \end{aligned}$$

For commuters we find

$$-(1 + \lambda)\overline{H}_w^c[V^c\Delta t^c + (1 + v)p\Delta m^c].$$

That is, one must compute the change in generalized travel costs where only the VAT rate is applied to the resource cost, this must be multiplied by the average number of travelers before and after and then corrected by the MCPF to take account of the labor market distortion.

Finally, for business travel we find

$$-(1 + \lambda)(1 + v)\overline{H}_w^f[p\beta\Delta t^f + p\Delta m^f].$$

So one must compute the change in generalized travel costs net of transport taxes, multiply by the average number of trips before and after, then convert to market prices and multiply by the MCPF. Note here again the

similarity with the formula for commuting as the value of time for commuters are assumed to be in market prices while the time costs for the firms  $p\beta\Delta t^f$  is in factor prices and therefore need to be corrected with the  $(1 + \nu)$ .

The contributions of all modes and routes must be summed to obtain the total effect.

## 4 Example

In this section we present a small numerical illustration of the application of the rules to the output of a traffic model. A further purpose of the illustration is to demonstrate the significance of accounting for the effect on the labor market.

We consider a traffic model with two routes,  $i = a, b$ , connecting two points (one origin and one destination). This is of course simplistic in relation to a real application but sufficient for our purposes. We need just consider leisure transport and commuting since the CBA rules for firms' transport are essentially identical to those for commuters. The two routes have identical characteristics ex ante and the travelers distribute evenly between them. The ex ante travel time for each route is  $t_i^x(s_0) = 1$  hour,  $x = n, c$ . The routes are both 100 kilometers long and both the resource cost and the tax per kilometer is 1 DKK. Thus  $m_i^x(s_0) = 100$  and  $\rho_i^x(s_0) = 100$ .

We now consider three cases where respectively the travel time, the transport cost and the transport tax is reduced by 10 per cent on route b. In all three situations, we assume the policy moves 10 per cent of traffic towards the improved route b such that the ex post split becomes 40 per cent on route a and 60 per cent on route b. We further assume that only the route choice, not the total demand for leisure travel, is affected by the policy; for commuting we have already assumed that the total travel demand is fixed from the perspective of the traffic model.

The numbers so far are available from the traffic model, perhaps supplemented with information on average costs per kilometer. We also need to know the distortionary loss  $\lambda$ , the indirect tax correction factor  $\nu$  and the

Table 1: Welfare effects in example

policy change	leisure travelers		commuters	
	$\lambda = 0$	$\lambda = 0.2$	$\lambda = 0$	$\lambda = 0.2$
$\Delta t_b^x = -10\%$	$5.5 + 0 + 0 = 5.5$	$5.5 + 0 + 0 = 5.5$	5.5	6.6
$\Delta m_b^x = -10\%$	$5.5 + 1.1 + 0.1 = 6.7$	$5.5 + 1.32 + 0.12 = 6.94$	6.6	7.92
$\Delta \rho_b^x = -10\%$	$5.5 - 5.5 - 0.5 = -0.5$	$5.5 - 6.6 - 0.6 = -1.7$	0	0

values of time  $V^x$ . We assume that these numbers are available from other sources. In the following we use  $v = 0.2$  corresponding to a realistic rate of VAT and  $V^n = V^c = 100$  DKK/hour. We normalize the total number of travelers with each purpose to 1. We calculate the total welfare effects for two assumptions on the distortionary loss,  $\lambda = 0$  and  $\lambda = 0.2$ , to illustrate the importance of the presence of tax distortions.<sup>8</sup>

We now get the results shown in Table 1. The results for leisure travelers are presented as the sum of three numbers. The first number is the change in surplus for travelers, the second is the direct effect on revenues and the third is the indirect effect on revenues due to the change in expenditure on leisure travel. The total welfare effect obtains by adding these numbers. For commuters we just present the result as one number.

Recall that the case for leisure travelers corresponds to the conventional analysis, such that comparison of the results with those for commuters shows the effects on the analysis of the inclusion of the labor market distortion.

First we comment on the effects of a 10 per cent travel time reduction. The effect for leisure travelers is just the direct effect, as there are no

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<sup>8</sup>The size of the marginal cost of public funds is hard to determine; the official guidelines of Denmark, Sweden and the US recommend values of  $\lambda$  between 0.2 and 0.3 meaning that the costs of a monetary unit of government spending is not 1 but 1.2-1.3. These values are currently applied without taking into account the distortionary effect on the labor market due to transport costs and the values are typically based on responses on the intensive margin. Kleven and Kreiner (2006) calculate values for the MCPF including the effects from the extensive margin under different assumptions of labor market elasticities. The results indicate that the value of 0.2 is a low estimate, even when ignoring intensive responses.



consequences for tax revenues when total leisure travel is constant. We find a total saving of 5.5 of which 5 is benefit to ex ante leisure travelers and 0.5 is benefit to new travelers who change from route  $\alpha$ . The same is true for commuters in the case with no distortion. However, when distortion is allowed for, a further benefit of the travel time reduction is revealed such that the benefit for commuters is  $\lambda$  times higher than the benefit for leisure travelers in identical circumstances. The reason is that travel time improvements increase the incentive for commuters to work and this increase in labor supply leads to an additional welfare gain usually not included in the CBA.

Next, we comment on the effects of a 10 per cent resource cost reduction. For the leisure traveler this represents a welfare gain which is slightly higher in the situation with tax distortions. While the direct effect for travelers is the same, the revenue effects are obviously affected by the tax distortions. The revenue effects give a welfare gain as the travelers save money on transport that is alternatively used on other consumption which is taxed with the VAT. Note that for commuters, the welfare effect in the situation without tax distortions is slightly smaller than for leisure travelers. The reason is that the indirect tax effect on revenue needs to be financed via changed income taxes. Turning to the situation with distortionary taxes the welfare effect is higher for commuters than for leisure travelers. The reason is now as before that the direct effect on the consumer surplus for commuters affects the supply of labor and thus leads to an additional gain.

Finally, we consider the effects of a 10 per cent transport tax reduction. Consider first leisure travel in the situation without distortion. The direct welfare gain of 5.5 is exactly counterbalanced by the direct revenue effect for the government. The increase in leisure travel leads to a loss of revenues through general indirect taxation worth 0.5, such that the net loss is 0.5. The size of the net loss depends on the assumptions we have made for this example concerning the demand reaction to the policy change and in general it is not the case that decreasing the tax on leisure travel will always lead to a net welfare loss as discussed in section 3.4.1.

Allowing for distortion increases the effect of the revenue loss for government and hence the welfare loss from the transport tax reduction for

leisure travelers becomes larger.

For commuters, the effect of changing the transport tax is zero, both with and without allowing for distortion. This is natural since the transport tax change is financed through the income tax and both taxes have exactly the same effect on commuters within the model.

Thus we have a large difference between the conventional analysis and the the present. The conventional analysis would indicate a welfare gain from increasing the transport tax in almost any circumstances, since the distortionary effect of the transport tax itself was not recognized. The present analysis shows that the welfare gain disappears when the distortionary effect of the transport tax is taken into account.

It is obvious from the tables above that the effects for travelers with different purposes must be treated differently as a consequence of their effect on labor supply and production.

## 5 Conclusion

We have derived simple rules for CBA that can be applied to the output of a traffic model and that account for distortion on the labor market in a consistent manner. For leisure transport, the rules are exactly the same as in a conventional analysis that includes the marginal cost of funds. For commuting and business travel including freight transport we find a new rule. The difference relative to the conventional analysis results from the assumption that income taxes and transport costs affect both the net wage and hence employment at the extensive margin. Thus transport costs have the same distortionary effect as income taxes. We have used Kleven and Kreiner (2006) to argue that this is a fair assumption.

Comparing the results obtained by the conventional rules and rules provided here for commuting and business travel, we find that the conventional CBA rules underestimate the welfare gains from reducing travel times or resource costs under realistic assumptions. The differences between the two sets of rules are substantial. It hence makes a large difference for the outcome of a CBA whether the distortionary effect of transport costs is taken into account.

The conventional CBA rules also indicate that changing transport taxes will have direct consequences for welfare through the distortionary effect of income taxes. However, there is no welfare effect when the distortionary effect of the transport tax is taken into account. It should be emphasized that there may in fact be indirect welfare effects of changing the transport tax for, say, commuters if the resulting change in behavior affects travel times and costs. These effects are handled by the traffic model.

A criticism that may be raised against our framework is the lack of feedback from the general equilibrium effects on employment to the traffic model. In the case of congestion there will be an effect on travel times and costs that we do not account for. This is unavoidable given that we consider the CBA as a separate calculation performed after running the traffic model. The issue is likely to be minor when the traffic project is local and the general equilibrium effects concern a whole country. It is important in our framework that there is a clear division between the tasks of the traffic model and of the general equilibrium model. If it is desired to have the traffic model also predict changes in volume of commuting and business travel then the rules derived here do no longer apply, while a host of issues arise on the modeling of production and employment within a traffic model.

The assumption that transport costs affect labor supply only at the extensive margin is important for the simplicity of the CBA rules that we derive. This simplicity we believe is crucial for the context that we consider where the CBA rules are to be applied to the output of a traffic model. It does however seem to be an interesting issue to pursue how transport costs interact with the labor supply decision both at the intensive and the extensive margin.

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