An evaluation of the performances of equity measures

Farideh Ramjerdi
Institute of Transport Economics
Post Box 6110 Ettersatd
N-0602 Oslo, Norway
Tel: +47 22573838
Fax: +47 22570290
E-mail: fra@toi.no

Abstract

Equity implications of transport policies, in particular congestion pricing, have been the focus of many recent studies. Some studies address the distributions of economic gains and losses among different groups of users, generally by income or by location, and propose how to calculate these. Others have focused on alternative schemes for recycling of transport revenues, commonly toll revenues, in order to address equity concerns. And some have concentrated on different stakeholders such as consumers, producers and operators, and subgroups among stakeholders that are affected differently by a transport policy. Eliasson and Lundberg (2002) provide a survey of these studies. There are not many studies that take up the quantification of inequality. Among these the EU funded research projects AFFORD, MC-ICAM and PROSPECTS (see Fridstrøm, et al 2000; Minken et al, 2002; MC-ICAM, 2003).

Equity considerations can be addressed by two alternative approaches. One approach is to respond directly to the distributional concerns by assuming an explicit form of social welfare function and the choice of a desired inequality aversion parameter. This approach requires a general equilibrium modelling approach. The second approach is to apply an inequality measure to a given pair of distributions of a variable that changes as the result of a policy, such as income, accessibility, etc. In this paper equity is addressed by the latter approach using a partial equilibrium model of transport for the calculation of the changes in income, accessibility and net benefit for different social groups.

The purpose of this paper is to demonstrate the challenges that arise in addressing equity with a partial equilibrium model of transport model. An overview of some equity measures and their properties is provided first. The performances of these equity measures are evaluated for alternative road-pricing schemes for Oslo.

This paper shows the sizes of the equity measures are quite sensitive to the level of spatial disaggregation and to the scale and translation in the measure of welfare. While it should in many cases be possible to pass judgment on which one of a set of alternative policies is the most equitable, relating the equity objective to a predefined value of any of these measures is not a desirable approach. Furthermore it is difficult to make a judgement about the equity implication of a policy on the basis of a single measure and without a thorough examination of several measures.

1. Introduction

Partial equilibrium models of transport or integrated transport and land use are most often used for the evaluation of the impacts of a toll scheme and the incidence of benefits and costs. These models do not capture the interactions between the transport sector and the rest of the economy. It is common to implicitly address these interactions by the use of a so-called “marginal cost of public funds” (MCF). Roughly speaking, the marginal cost of public fund is the cost to society of raising a EURO’s worth of public revenue by distortionary taxation. It is assumed that the distortionary tax that will have to be used is the income tax. However, different tax instruments, including the pricing instruments of transport, will have different MCFs. From an efficiency point of view, the instrument with the least MCF should be used. But efficiency is not the only concern. As Sandmo (2000) points out, a main reason for distortionary taxes is to address redistribution, otherwise uniform or arbitrary lumps-sum taxes could have been levied. The redistribution impacts depend not only on which tax instrument is used but also on how revenue is recycled, e.g., used in the public sector or recycled to the households. The distortions in the rest of the economy make the secondary effects of transport policies on the rest of the economy relevant.

A general equilibrium framework addresses the interactions of the transport sector with the rest of the economy explicitly. An example of this type of models is TRENEN (see for example Proost and Van Dender, 2002). It however lacks important details in the transport and land use markets. The level of detail among partial equilibrium transport models varies with respect to geographical detail, presentation of the transport networks, alternative modes of travel, time periods (usually peak and off peak) as well as the segmentation of the market by travel purposes. Behavioural responses with different time dimensions such as route choice, mode and destination choices and trip frequency are usually captured in transport models. The architecture of these models can be exploited to apply the models for different time horizons from the very short to medium run. The use of disaggregate data in the estimation allows individual and household socio-economic characteristics to enter the model formulation as explanatory variables. Consequently it is possible to apply this class of models to evaluate the differences in responses of different segments of a population to a transport policy. While partial equilibrium models must inevitably represent economy-wide distortions and distributional impacts in a coarse way, this level of detail in the representation of the transport market is a strong point with respect to equity analysis of policies. An example of this type of models is RETRO (see for example Fridstrøm, et al, 2000).

This paper demonstrates some of the challenges that arise in analysing equity implications of a transport policy with a more traditional transport model system. The next section focuses on a review of some equity measures and their properties. In section three the performances of equity measures are examined in two case studies for Oslo. The first case study is taken from the AFFORD project (see Fridstrøm, et al, 2000). The second case study for Oslo is from a more recent study (see Ramjerdi et al, 2005). Section four present some results and conclusions.

2. Equity and accessibility measures

The most central issue in the assessment of equity is related to how equity is defined. Equity can be defined along many dimensions such as justice, rights, treatment of equals, capability, opportunities, resources, wealth, primary goods, income, welfare, utility and so on (see Sen, 1982, 1992). Sen (1992) states that every normative social theory that has stood the test of time demand equality of something that is regarded as particularly important in that theory. Sen continues by suggesting that demanding equality in one space implies inequality in some other space. An important ethical issue is related to the *equality of consideration*. Sen suggests that "the need to defend one's theories, judgements, and claims to others who may be directly or indirectly involved, makes the equality of consideration at some level a hard requirement to avoid" (Sen, 1992, p18). Furthermore the relative advantages and disadvantages of people can be judged in terms of many different variables, *e.g.* their respective incomes, wealth, utilities, resources, liberties, rights, quality of life, and so on. "The plurality of variables on which we can possibly focus (the *focal variables*) to evaluate interpersonal inequality makes it necessary to face, at a very elementary level, a hard decision regarding the perspective to be adopted. This problem of choice of the `evaluative space` (that is, the selection of the relevant focal variables) is crucial to analysing inequality" (Sen, 1992, p20). It is not the purpose of this paper to provide an overview how different social philosophies have defined equity and to compare these. It is however important to emphasis that the different aspects of equity are important for different groups in society and it is important to provide measures for the evaluation of their concerns and to reflect their views.

In order to address equity a unit of analysis and the variable along which equity is to be analysed have to be defined. In a social context the unit of analysis can be an individual or a collective unit such as a nuclear family, women, elderly, disabled, a region, etc. The choice of the unit depends on the interpretation of the inequality measurement. In some context it is natural to adopt an individual as the unit, for example when we are looking at exposure to pollutants. In other contexts, e.g. when we are examining the distribution of wealth or income, it might be more useful to adopt a collective unit such as a household. Furthermore it is possible to address inequalities along a certain dimension in terms of between- and within groups such as between genders, regions, etc. Coherence and homogeneity are the important criteria in the selection of collective unit.

2.1 Properties of equity measures

Different measures of inequality reflect different perception of inequality. The sets of weights that different views attach to transfers at various points in a distribution are different. That can result in contradictory ranking of a given pair of distributions (see Kolm, 1969; Atkinson, 1970; Sen, 1973). In this sense inequality measures have both normative and descriptive content. These measures can be used to describe the differences in a population with respect to a given variable such as income, but they can also represent the manner in which these differences should be measured. There are numerous axioms that put specific requirements on the properties of a measure of inequality. In the following we summarize a number of these axioms (see Harrison and Seidl 1994; Myles, 2000). These axioms are used for the construction of the axiomatic measures of inequality.

The symmetry or anonymity axiom requires the inequality measure for a given income distribution in a given population not to be affected by the order in which the individuals are labelled. In other words it is not important who is rich and who is poor. This axiom seems very obvious. All the measures that are described in the followings sections satisfy this axiom.

The axiom of transfer or *Pigou-Dalton principle* says that a transfer of income from a rich person to a poor person should reduce the measured inequality as long as the income of the rich person stays higher than the poor person after the transfer. This view was originally expressed by Pigou in 1912 (Pigou, 1954) and shared by Dalton in 1920 (Dalton, 1920). The Pigou-Dalton principle is an important property that any acceptable measure of inequality should satisfy.

The principle of population requires the inequality measure to be independent of the size of the population.

The scale invariance axiom or *relative inequality aversion axiom* demands that the measured inequality should not change if all members of a population get the same proportional increase in incomes. Kolm (1976a, 1976b) regards this as a (politically) rightist view.

The translation invariance axiom or *absolute inequality aversion axiom* requires that the measured inequality does not change by changing all incomes by the same amount as long as the changes do not lead to a negative income. This is regarded as a (politically) leftist view.

The decomposability axiom requires that there should be a coherent relationship between inequality in the whole population and its constituent parts. The basic idea is that one should be able to define the inequality measure of the total population as a function of inequality within its constituent parts and inequality between the subgroups.

2.2 Some inequality measures

Inequality measures are often classified as statistical, welfare or axiomatic (see for example Myles, 2000 and Cowell, 1977). *Statistical measures* examine the distribution of any variable in a given population such as income. Examples of these are; range, variance, measure of variation, log variance, Gini measure and Theil's entropy measure. *Welfare measures* rely on welfare economics and incorporate equity concerns into a welfare function. A*xiomatic measures* are derived by addressing the properties that a satisfactory measure ought to have. These measures can be applied to the evaluation of inequality of any vector or distribution of observations, even to non-economic data such as the distribution of the ambient level of pollutants or accessibility over an area. The following measures are examined in this study.

1. Range, R, defined as

$$R = Y_{max} - Y_{min} \qquad (1)$$

2. Variance, V, defined as

$$V = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \bar{Y})^2 \qquad (2)$$

3. Coefficient of variation, c, defined as

$$c = \frac{\sqrt{V}}{\bar{Y}} \qquad (3)$$

4. Relative mean deviation, M, defined as

$$M = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Y_i}{\bar{Y}} - 1\right| \qquad (4)$$

5. Logarithmic variance, v, defined as

$$v = \frac{1}{n}\sum_{i=1}^{n}\left(\log(\frac{Y_i}{\bar{Y}})\right)^2 \qquad (5)$$

6. Variance of logarithms, v_l, defined as

$$v_l = \frac{1}{n}\sum_{i=1}^{n}\left(\log(\frac{Y_i}{\overline{Y}_{\log}})\right)^2 \qquad (6)$$

7. The Gini measure, G, defined as

$$G = \frac{1}{2n^2.\overline{Y}}\sum_{i=1}^{n}\sum_{j=1}^{n}| Y_i - Y_j | \qquad (7)$$

8. The Theil's entropy measure, T, defined as

$$T = \frac{1}{N}\sum_{i=1}^{N}\frac{Y_i}{\overline{Y}}\log(\frac{Y_i}{\overline{Y}}) \qquad (8)$$

9. The Atkinson index, A_ε, defined as

$$A_\varepsilon = 1 - \left[\frac{1}{n}\sum_{i=1}^{n}\left[\frac{Y_i}{\overline{Y}}\right]^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \qquad (9)$$

10. Kolm's measure of inequality, K_α, defined as

$$K_\alpha = \frac{1}{\alpha}\log\left(\frac{1}{N}\sum_{i=1}^{N}\exp(\alpha(\overline{Y} - Y_i))\right) \qquad (10)$$

In the above measures

- Y is a measure of welfare
- n is the number of observations on welfare
- $\overline{Y}$ is the mean level of welfare
- $\overline{Y}_{\log}$ is the mean level of log of welfare

ε and α in Atkinson and Kolm measures are parameters that address inequality aversion and ε and $\alpha > 0$.

The first 8 measures are classified as statistical measures, while the last 2 measures (Atkinson and Kolm) are welfare measures. The following table summarises some of the properties of these measures.

Table 1 A summary of the properties of inequality measures

Measure	Definition	Some important properties		
		Transfer	Scale invariance	Translation invariance
Variance	Eq. (2)	Yes	No	Yes
Coeff. Of variation	Eq. (3)	Yes (weak)	Yes	No
Relative mean deviation	Eq. (4)	Yes	Yes	No
Logarithmic variance	Eq. (5)	No	Yes	No
Variance of logarithms	Eq. (6)	No	Yes	No
Gini	Eq. (7)	Yes (weak)	Yes	No
Theil's entropy	Eq. (8)	Yes	Yes	No
Atkinson-Kolm	Eq. (9)	Yes	Yes	No
Kolm	Eq. (10)	Yes	No	Yes

The impacts of a package of instruments can be measured using non-economic data. An example of the application of the equity measures to non-economic data is related to the changes in the distribution of emission of pollutants over the area of study. It might even be feasible to evaluate the changes in terms of within and between segments of the population. The segments can be defined in terms of the socio-economic characteristics of the population or by locations in the study area. A decomposable measure is necessary for this purpose (see for example Myles, 2000 and Cowell, 1977).

The incidence of net efficiency gains of a transport policy might be different for different segments of a population or over a geographical area. It was suggested earlier that for a correct calculation of the net efficiency gains a spatial general equilibrium model is necessary. Addressing the interactions of the transport market with the rest of the economy, especially with the labour market, is crucial for a correct calculation of the distribution of the net efficiency gains among a population or over a region. It is, however, possible to use different measures of inequality or accessibility measures in order to obtain some indication of the distribution of the incidence of the net benefits. Equity and accessibility measures only suggest the likely direction of impacts and should be treated as such. The ex-post equity analysis provides some information on how to recycle revenues to address equity considerations.

2.3 Some accessibility measures

Two alternative approaches will be used for measuring accessibility (see Geurs and Ritsema van Eck, 2001; Baradaran and Ramjerdi, 2002, for a review of accessibility measures).

Gravity or opportunities approach defined by:

$$G_i = \sum_{j \in L} \frac{W_j}{f(c_{ij}, \beta)} \qquad (11)$$

where

W_j stands for the mass of opportunities available to i at location j

$f(c_{ij},\beta)$ is the deterrence function = $f(c_{ij},\beta) = e^{\beta c_{ij}}$

β is assumed to equal to 0.35

c_{ij} is the generalised cost of travel by car between i and j.

Three alternative accessibility measures are constructed using this approach as follows

G_Emp	in which W_j is equal to the total employment at j
G_65+	in which W_j is equal to the total population over 65 years of age at j
G_20-65	in which W_j is equal to the total population 20-64 years of age at j
G_W	is which W_j is equal to the female population at j

“Logsum” measure is used defined as:

$$\log sum_i^n = \underset{i,j \in L}{Max}\, U_{j|i}^n = \frac{1}{\mu} \ln \sum_{j \varepsilon L} \exp(\mu(v_j^n - c_{ij}^n)) \qquad (12)$$

where

$\log sum_i^n$ is the measure of accessibility at location i for individual n

$U_{j|i}^n$ is the utility of travel to location j given the individual n is located at i

v_j^n reflects attraction at j

c_{ij}^{n} is the travel cost between i and j

μ is a positive scale parameter that is estimated

3. The performance of the equity measures

The greater Oslo area has a population of about one million with an area of 5,305 km^2. The population density is about 140 inhabitants/km^2. Oslo city has a population of about 512,0000. The Oslo toll ring was established in 1990 as a financing scheme. Originally, the toll revenue, supplemented by about equal funds from the central government, was to finance the “Oslo Package” (now referred to as “Oslo Package 1”), comprising some 50 new road projects. It is estimated that by 2007 the total contribution of the scheme to Oslo Package 1 will amount to NOK 9.1 billion (2002 NOK), approximately 15-20 per cent above the initial estimate. In 2000 the Parliament approved an increase in the toll fee for financing an investment package on public transport projects, referred to as “Oslo Package 2”.

There is much debate and some interest in changing the direction of the scheme to a congestion pricing scheme from 2008. Amongst the different alternatives that have been evaluated for Oslo, there is a time differentiated toll scheme with the purpose of reducing car traffic during peak periods. Revenues would be allocated to public transport and to the extension and improvement of roads in the region. The Oslo scheme is most likely to continue in some form or other after 2007. The new scheme is often referred to as “Oslo package 3”. Equity has been an important concern in the debate on the new package.

In the following sections the performances of the equity measures will be evaluated in two case studies for Oslo. The instruments and their levels and the packages used in these case studies do not reflect precisely any of the current proposals for the future of the Oslo scheme. The lessons are however valid for the evaluation of equity implications of any package of instruments.

3.1 Framework for evaluation

A multi-modal transport model RETRO is used in this study (Ramjerdi and Rand, 1992; Vold, 2003). RETRO has the following sub-models:

- i) Disaggregate and aggregate license holding models
- ii) Disaggregate car ownership models
- iii) Disaggregate models for travel frequency and models for mode and destination choices
- iv) Segmentation model
- v) Network model

EMME/2, a software package is used for the network model. The number of zones is 438. In this case study it is assumed that the land use changes are exogenously defined.

The alternative scenarios are evaluated according to an objective function that accounts for the net benefits of all the affected actors, users, non-users, producers and government, defined as

$$OF = \sum_{t \in t^*} \frac{1}{(1+r)^t} (CS_t + PC_t + MCF_t * GS_t + Env_t + \gamma_t g_t) \qquad (13)$$

where

OF is the net benefit
t^* is the horizon year
r is a discount rate
CS_t is the change in the consumer surplus in year t
PS_t is the change in the producer surplus in year t
GS_t is the change in the government surplus in year t
MCF_t is the marginal cost of public funds in year t
Env_t is the external costs defined as accident, noise and pollution costs and other external effects
γ_t is the shadow cost of CO_2 emission, reflecting national CO_2 target for year t,
g_t is the amount of CO_2 emissions in year t,

The rule-of-half is used for the calculation of the consumer surplus. The changes in the producer surplus (revenues net of costs) should be calculated for all the transport operators. Since toll and parking operators in this study are government agencies, these will be addressed under the government surplus. The public transport operators must earn a surplus after subsidy. Hence their surplus is also accounted for under the government surplus. The tax revenue associated with car use and car ownership will be included in the government surplus.

Tables 2 and 3 show the unit values that have been adopted in this case study. These are based on recommended Norwegian values in urban areas (Eriksen et al, 1999)

Table 2 Values of externalities (in Euro/vehicle kilometre)

Mode	Emissions (other than CO_2)	Noise	Accidents	CO_2
Car (average)	0.025	0.017	0.027	0.011
Public Transport (average for bus, and light rail)	0.304	0.170	0.061	0.066

Table 3 Value of travel time (in Euro/hour)

Mode of travel	Car	Public transport
In vehicle time	5.64	4.70
Wait and transfer time	-	5.64
Auxiliary time	-	5.64

3.2 The first case study for Oslo

The first case study is taken from the AFFORD project (see Fridstrøm, et al, 2000). In the AFFORD project a number of packages of instruments are calculated in order to maximise the objective function described by Equation 13. The optimizations are carried out under two alternative assumptions; MCF=1.0 and MCF=1.25. The Gini coefficient and the Lorenz curve are used for the evaluations of the equity implications of these packages. For the purpose of this study, i.e., an evaluation of the performances of equity measures, only one of these packages is selected. This package comprises of a time differentiated (peak and off-peak) toll ring scheme (the present location) and time differentiated (peak and off-peak) parking fees and for MCF=1.0 (scenario P21). We call this the policy scenario. The toll fee in this scenario is about 21.5 NOK during peak periods and no charge during the off-peak. The parking fee is slight higher during peak periods (1.025 time the present levels) and slightly lower during the off-peak (0.996 times the present levels). The policy scenario is calculated under alternative assumptions about the recycling scheme: no recycling of the revenue, a flat recycling and a proportional recycling of the revenue among households. The revenue generated is kept by the public treasury in the no recycling scheme. In the flat recycling scheme, the revenue is distributed among the households by the same nominal amount of money. In a proportional recycling scheme, the revenue is distributed among the households in amounts proportional to each household's initial income, i.e. as a given percentage point income tax relief. Table 4 shows the income distributions in the reference scenario and in the policy scenario under alternative assumptions about the recycling of the revenue. For more information about the performances of these scenarios see Fridstøm, et al (2000).

Table 4. Income distribution in the reference scenario and the policy scenario under alternative assumptions about recycling

	Income/consumption unit. Euros/year in scenario			
Income group	Reference	No recycling	Flat recycling	Proportional recycling
1	1735.75	1719.04	1800.62	1726.42
2	7616.81	7592.89	7652.53	7625.25
3	11368.78	11328.95	11397.92	11377.25
4	14830.40	14777.62	14846.38	14840.63
5	18023.72	17965.65	18035.04	18042.22
6	21163.99	21096.63	21166.25	21186.54
7	25347.27	25274.57	25339.42	25382.25
8	41805.57	41723.34	41787.44	41900.94

Table 5 shows the performances of the equity measures described in Section 2.2 when applied to income distributions presented in Table 4. It is important to point out that the scale of income is quite important in a number of these measures. The scale of income used for the calculation of these measures is in Euros/year, except in the calculation of the Kolm measure, where the scale is in 10,000 Euros/year. This scale of income makes the Kolm measures comparable to the Atkinson measures in size. Note that the Atkinson measure does not depend on the scale while the Kolm measure does.

A first task is to compare the performances of these measures when comparing the reference scenario and the policy scenario with no recycling. The average income of all income groups decreases in the policy scenario with no recycling. However the low income groups loose less proportional to their incomes than the high income groups. These shifts in income distributions are reflected in all measures. Mean, coefficient of variation, relative mean deviation, logarithmic variance, Atkinson measures and the Gini coefficient suggest that the policy scenario with no recycling has worsens the income distribution. Range, variance, variance of logarithms, the Theil measure and Kolm measures suggest that the policy scenario with no distribution improves the income distribution.

The comparison of measures of equity for the reference scenario and the policy scenario under alternative recycling suggests that the policy scenario with a flat recycling scheme produces the most desired income distribution. The exceptions are the mean and the variance of logarithms. Coefficient of variation, relative mean deviation, logarithmic variance, the Theil measure, Atkinson measures, and the Gini coefficient suggest that the policy scenario with no recycling produces the most undesirable income distribution. Note that the Atkinson measures and the Gini coefficients are almost similar for the no recycling and the proportional recycling schemes. Range, variance and Kolms measures suggest that the policy scenario with proportional recycling result in the worst income distribution.

These results suggest that for the evaluation of the equity implications of a transport policy, it is desirable to look at a number of equity measures rather than using a single measure.

Table 5. Performances of some equity measures

	Scenario			
Equity measure	Reference	No recycling	Flat recycling	Proportional recycling
Mean	17737	17685	17753	17760
Range $Y_{max} - Y_{min}$	40070	40004	39987	40175
Variance	132062507	131596975	131533921	132719502
Coefficient of variation	0.647919	0.648667	0.646014	0.648664
Relative mean deviation	0.498891	0.499310	0.497310	0.499308
Logarithmic variance	0.170700	0.171504	0.166544	0.171501
Variance of logarithms	12.435540	12.425635	12.447230	12.437219
Theil	0.094088	0.094292	0.093347	0.094291
Atkinson				
ε=0.0001	0.000021665	0.000021712	0.000021494	0.000021712
ε=0.001	0.000216678	0.000217149	0.000214972	0.000217147
ε=0.005	0.001084048	0.001086404	0.001075495	0.001086394
ε=0.01	0.002169744	0.002174462	0.002152581	0.002174442
ε=0.05	0.010476763	0.010499671	0.01039219	0.010499573
ε=0.1	0.020022158	0.020066296	0.019856201	0.020066109
Kolm				
α =0.0001	0.000028676	0.000028575	0.000028561	0.000028819
α =.001	0.000286689	0.000285678	0.000285541	0.000288114
α =0.005	0.001431813	0.001426763	0.001426078	0.001438924
α =0.01	0.002859550	0.002849459	0.002848090	0.002873730
α =0.05	0.070674059	0.070423717	0.070389532	0.07102009
α =0.1	0.278636185	0.277644814	0.277508219	0.279978572
Gini	0.353895	0.354231	0.352785	0.354230

3.3 A second case study for Oslo

The second case study is taken from the SPECTRUM project (see Timms et al, 2005). The objective function described by Equation 13 is used to evaluate a reference scenario and a number of packages of instruments for Oslo. These packages are calculated with different assumptions about the value of MCF. Among these, a package of instruments comprising a time differentiated toll ring scheme (about 35 NOK during the peak periods about 14 NOK during the off-peak), an increase in fuel taxes by 50% and an increase in public transport frequency of services by 5.8 percent performs best. Table 6 shows a summary of the performance of the policy scenario compared with the reference scenario. It is assumed that MCF=1.0. For more information see Ramjerdi et al (2005).

Table 6. The performance of the policy scenario compared with the reference scenario (million Euro/year)

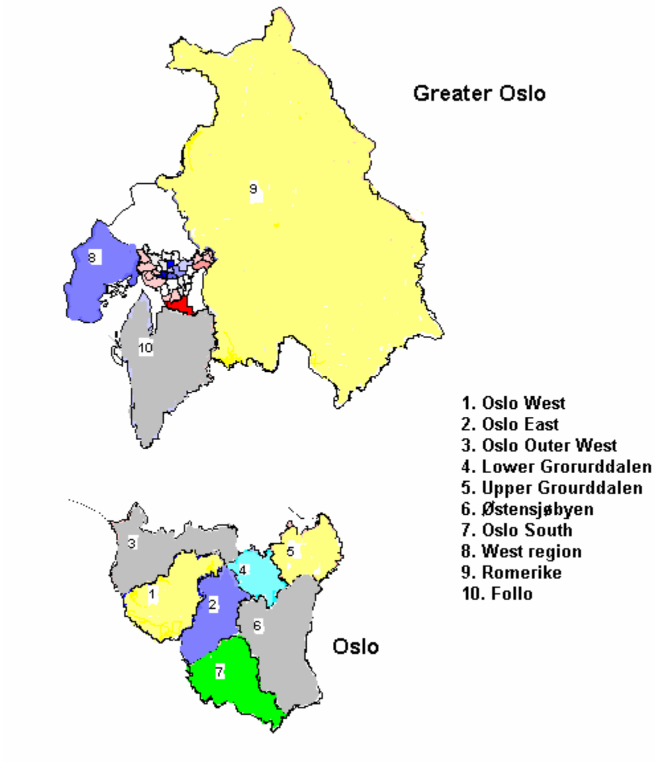
Consumer surplus	**-464.5**
Government surplus	
Fuel tax	343.0
Annual car taxes	-30.6
Toll revenue (net)	158.7
Parking revenue	-4.1
Public transport revenue	23.0
PT investment	-19.4
Total	**470.6**
Externalities (emission of pollutions, noise and accident)	**38.0**
CO2	**6.0**
Total	**50.1**

Table 7 shows the differences between the accessibility measures in the policy and the reference scenarios. Figure 1 shows the different areas in the Oslo region. As can be expected, all the differences are negative in all areas in the Oslo region. An increase in fuel tax and a toll will drastically decrease accessibility by car (G_Emp, G_W, G_65+ and G_20-65). Note that G_W, G_65+ and G_20-65 measures indicate the accessibility of a particular segment of the population to the different areas in the Oslo region while G_Emp indicates accessibility to the employment in different locations. All these measures have similar patterns. They all indicate that the accessibility by car to Upper Groruddalen will decrease most for all the segments of the population. Accessibility for employment (G_Emp) and accessibility for the population of age 20-65 (G_20-65) have similar patterns.

Table 7. Differences between the accessibility measures in the policy and the reference scenarios

	Employment G_Emp	Women G_W	Age over 65 G_65+	Age 20-65 G_20-65	Logsum
1. Oslo West	-1.11	-0.82	-0.29	-1.31	-5.10
2. Oslo, East	-2.19	-1.30	-0.50	-2.01	-5.68
3. Oslo, outer West	-7.15	-5.96	-2.06	-9.57	-5.74
4. Lower Grorurddalen	-4.79	-3.00	-1.15	-4.66	-5.49
5. Upper Groruddalen	-16.09	-18.85	-6.24	-29.98	-8.72
6. Østensjøbyen	-7.86	-12.37	-6.22	-18.06	-4.81
7. Oslo South	-1.16	-3.65	-1.54	-5.53	-9.13
8. West region	0.00	0.00	0.00	-0.01	-3.67
9. Romerike	-0.24	-0.42	-0.14	-0.64	-7.92
10. Follo	-5.03	-8.89	-2.75	-14.05	-4.89

Figure 1. The greater Oslo area



A main problem with the gravity approach is that the scale of the accessibility measures is ordinal. The "logsum measure" closely compares with the changes in the consumer surplus. It also captures the effects of provision of the public transport services. This measure suggests that the benefits in the policy scenario are not evenly distributed and hence have potential adverse distributional effect.

To evaluate the significance of the observed variations in the geographical distributions of welfare (captured by the logsum measure) the equity measures described in section 2.2 are used. Table 8 shows a summary of some of these inequality measures applied to the geographical distributions of welfare over 49 zones that make up the Oslo region. While almost all measures are quite similar in both scenarios, they suggest that the geographical distribution of welfare is more even in reference scenario than in the policy scenario.

Table 8. Summary of some inequality measures in the policy and the reference scenarios for the Oslo region (49 zones)

49 zones	Policy scenario	Reference scenario
Mean	498.35	504.89
Range $Y_{max} - Y_{min}$	360.67	361.56
Variance	5175.71	5072.69
Coefficient of variation	0.144	0.141
Relative mean deviation	0.1070	0.1118
Logarithmic variance	0.0059	0.0056
Variance of logarithms	5.1210	4.5333
Theil	0.2480	0.2366

Table 9 shows the summary of all the described inequality measures applied to the geographical distributions of welfare over 10 zones that represent the Oslo region. A comparison of the measures in this table with the corresponding measures in Table 8 shows that the level of zonal aggregation affects the size of most measures. This is partly due to the approximations in aggregation (not properly weighted) as well as the properties of the measures. This table also suggests most measures are quite similar in both scenarios and that the geographical distribution of welfare is more even in reference scenario than in the policy scenario. Table 9 also shows the sensitivity of the Atkinson and Kolm measures to the inequality aversion parameter. The Atkinson measure is more sensitive to the value of the inequality aversion parameter than the Kolm measure.

While the property of a measure provides information about its change with a translation, it is relevant to get some sense of the level of change, if any. To get an understanding of the size of the change, the measures were calculated for both scenarios (reference and policy scenarios) after a translation. The translation was performed by subtracting from welfare (logsums) 443 units. The aim was to avoid negative values for the welfare measure as the result of the translation and to obtain small values for the level of welfares. Table 10 shows the summary of the results.

Table 9 Summary of inequality measures in the policy and the reference scenario for the Oslo region (10 zones)

10 zones	Policy scenario	Reference scenario
Mean	519.09	525.29
Range. $Y_{max} - Y_{min}$	115.20	113.01
Variance	1714.08	1710.49
Coefficient of variation	0.0798	0.0787
Relative Mean Deviation	0.0703	0.0697
Logarithmic variance	0.0013	0.0013
Variance of logarithms	5.2007	5.2205
Theil	0.0014	0.0013
Atkinson		
$\varepsilon = 0.0001$	0.0000003	0.0000003
$\varepsilon = 0.001$	0.0000033	0.0000032
$\varepsilon = 0.005$	0.0000163	0.0000616
$\varepsilon = 0.01$	0.0000326	0.0001260
Kolm		
$\alpha = 0.0001$	0.0373	0.0372
$\alpha = 0.001$	0.3765	0.3757
$\alpha = 0.005$	1.9607	1.9563
$\alpha = 0.01$	4.0774	4.0663
Gini	0.04199	0.04118

Table 10 Summary of inequality measures in the policy and the reference scenario for the Oslo region (10 zones) after a translation in welfares by 443 units.

10 zones & Trans 443	Policy scenario	Reference scenario
Mean	76.09	82.29
Range, $Y_{max} - Y_{min}$	115.20	113.01
Variance	1714.08	1710.49
Coefficient of variation	0.5441	0.5026
Relative Mean Deviation	0.4796	0.4451
Logarithmic variance	0.6310	0.1687

Variance of logarithms	2.5538	2.5326
Theil	0.9287	0.7264
Atkinson		
ε = 0.0001	0.000021	0.000017
ε = 0.001	0.000214	0.000167
ε = 0.005	0.001072	0.000838
ε = 0.01	0.002150	0.001679
Kolm		
α= 0.0001	0.0373	0.0372
α=0.001	0.3765	0.3757
α= 0.005	1.9607	1.9563
α= 0.01	4.0774	4.0663
Gini	0.2860	0.2626

A comparison of Tables 9 and 10 suggests that the size of the measures that are not translation invariant change significantly. These measures suggest that the geographical distribution of welfare is more inequitable in the policy scenario than in reference scenario once the translation is performed.

While this exercise suggests that accessibility and equity measures can be applied to the evaluation of potential changes in the distribution of welfare caused by a package of instruments, one needs to apply them cautiously. Accessibility measures, other than a logsum measure, are ordinal and hence it is problematic to apply equity measures to examine changes in their distributions.

The logsum measures in Table 7 suggest that the distribution of benefits of the package in the policy scenario is potentially uneven over the Oslo area. The difference between the different areas is as high as 210 Euro/year for an average traveller. Yet, the sizes of the different equity measures (see Tables 8, 9, and 10) vary significantly as the result of the level of spatial disaggregation and a translation in the measure of welfare. Similarly some of the measures are quite sensitive to the scale of the welfare measure. This illustrates that relating the equity objective to a predefined value on any of these measures is not desirable approach. Once we have defined the units to be compared and the distributional concern to be addressed, it will, however, often be possible to rank alternatives with respect to equity. Furthermore, it is difficult to make a judgement about the equity implication of a policy on the basis of a single measure and without a thorough examination of several measures and their implications.

This exercise relies on a partial equilibrium transport model and ex-post evaluation of the equity implication of a package of instruments. Nonetheless, the lessons can be extended to a general equilibrium approach where an explicit form of social welfare function and an inequality aversion parameter is used to address equity concerns. Table 8 shows that Atkinson measures with aversion parameters of up to 0.001 favour the reference scenario for equity. With aversion parameters of larger than 0.001 the policy scenario becomes the favoured scenario. Hence it is important to explore the implications of the aversion parameter, possibly, in the form of a sensitivity analysis.

6. Some conclusions

Partial equilibrium models of transport or integrated transport and land use models are the most commonly used planning tools for the evaluation of the impacts of transport policies with respect to efficiency and equity. The lack of spatial details in general equilibrium models limits their applications. The main aim of this paper is to illustrate some important issues related to the evaluation of equity using a partial equilibrium model of transport with examples from Oslo.

Equity and accessibility measures can only provide information about the potential distribution of welfare among a population or over a geographical area. The size of the equity measures is quite sensitive to the level of spatial disaggregation and to the scale and translation in the measure of welfare. While it should in many cases be possible to pass judgment on which one of a set of alternatives is the most equitable, relating the equity objective to a predefined value of any of these measures is not a desirable approach. Furthermore it is difficult to make a judgement about the equity implication of a policy on the basis of a single measure and without a thorough examination of several measures.

Accessibility measures, other than a logsum measure, are ordinal and hence it is problematic to apply equity measures to examine the changes in their distributions.

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