Equity Measures and Their Performance in Transportation

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This paper aims at equity implications of transportation policies by using a range of equity measures in two case studies. Different measures of inequality embrace different normative judgments. Early studies have warned about placing too much trust in a single measure. One approach is to address equity considerations by assuming an explicit form of social welfare function and the choice of a desired inequality aversion parameter. A second approach is to apply an inequality measure to a given pair of distributions of a variable (e.g., income and accessibility) that changes as the result of a policy. The latter approach is adopted in this paper. A partial equilibrium model of transportation is used for the calculation of the changes in income, accessibility, and the net benefit for different social groups. This paper demonstrates the challenges that arise in addressing equity with a partial equilibrium model of transportation. 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, Norway. The paper illustrates that relating the equity objective to a predefined value of any of these measures is not desirable. It is difficult to make a judgment about the equity implication of a policy on the basis of a single measure and without a thorough examination of several measures. The paper also shows that the sizes of the equity measures are quite sensitive to the level of spatial disaggregation.

Partial equilibrium models of transportation or integrated transportation 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 transportation sector and the rest of the economy. It is common to address these interactions implicitly by the use of the so-called marginal cost of public funds (MCF). Roughly speaking, the MCF is the cost to society of raising a euro's worth of public revenue by distortional 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 transportation, 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 (*1*) points out, a main reason for distortionary taxes is to address redistribution; otherwise, uniform or arbitrary lump sum taxes could be levied. The redistribution impacts depend not only on which tax instrument is used but also on how revenue is recycled (i.e., used in the public sector or recycled to households). The distortions in the rest of the economy make relevant the secondary effects of transportation policies on the rest of the economy.

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A general equilibrium framework addresses the interactions of the transportation sector with the rest of the economy explicitly. It however lacks important details in the transportation and land use markets. The level of detail among partial equilibrium transportation models varies with respect to geographical detail, presentation of the transportation networks, alternative modes of travel, time periods, and the segmentation of the market by travel purposes. Behavioral responses with different time dimensions, such as route choice, mode and destination choices, and trip frequency, are usually captured in transportation models. The architecture of these models can be exploited to apply the models for different time horizons from the extremely short to the medium run. The use of disaggregate data in the estimation allows individual and household socioeconomic 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 transportation policy. While partial equilibrium models must inevitably represent economywide distortions and distributional impacts in a coarse way, this level of detail in the representation of the transportation market is a strong point with respect to equity analysis of policies.

This paper demonstrates some of the challenges that arise in the analysis of equity implications of a transportation policy with a transportation model system. The remainder of the paper is structured as follows: first, a review of some equity measures and their properties, then, an examination of performances of equity measures in two case studies for Oslo, and finally, presentation of some conclusions.

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 (*2, 3*). Sen (*3*) states that every normative social theory that has stood the test of time demands equality along some dimension that is regarded as particularly important in that theory. Sen also suggests 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, judgments, and claims to others who may be directly or indirectly involved makes the equality of consideration at some level a hard requirement to avoid" (*3,* p. 18). Furthermore, the relative advantages and disadvantages of people can be judged relative to many different variables (e.g., their respective incomes, wealth, utilities, resources, liberties, rights, quality of life, and so on), as Sen notes: "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" (*3*, p. 20). It is not the purpose of this paper to provide an overview of the ways in which different social philosophies have defined equity and to compare these. It is however important to emphasize 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.

To address equity, a unit of analysis and the variable along which equity is to be analyzed 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, the elderly, the disabled, or a region. The choice of the unit depends on the interpretation of the inequality measurement. In some contexts, it is natural to adopt an individual as the unit, for example, when exposure to pollutants is being examined. In other contexts, such as when the distribution of wealth or income is being studied, 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 as they occur between and within groups, such as between genders, regions, and so on. Coherence and homogeneity are the important criteria in the selection of a collective unit.

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 difference can result in contradictory ranking of a given pair of distributions (*4–6*). In this sense, inequality measures have both normative and descriptive content. These measures can be used to describe the differences in a population relative 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. The following discussion summarizes a number of these axioms (*7, 8*), which 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 labeled. In other words, it is not important who is rich and who is poor. This axiom seems obvious. All the other axioms and principles that follow satisfy this axiom.
- The axiom of transfer or the 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 that of the poor person after the transfer. This view was originally expressed by Pigou in 1912 (*9*) and shared by Dalton in 1920 (*10*). 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 (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 (*11, 12*) regards this as a (politically) rightist view.
- The translation invariance (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 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 subgroups.
- The important Lorenz dominance axiom requires that Lorenz curves of the distributions do not intersect. There is some consensus that if Lorenz dominance curves of distributions do not intersect, the following statement holds: "All measures of relative inequality will then agree on the ranking" (*13*, p. 107). In the next section, some of these measures are described.

Some Inequality Measures

Inequality measures are often classified as statistical, welfare, or axiomatic. [Examples are available elsewhere (*8, 14*).] Statistical measures examine the distribution of any variable, such as income, in a given population. Examples of these measures 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. Axiomatic 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 noneconomic data, such as the distribution of the ambient level of pollutants or accessibility over an area.

Table 1 shows the measures examined in this study and summarizes their properties. The first eight measures in the table are classified as statistical measures, while the last two (Atkinson and Kolm) are welfare measures. In the measures described in Table 1

- 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 the Atkinson and Kolm measures are parameters that address inequality aversion, and both ϵ and $\alpha > 0$.

The impacts of a package of instruments can be measured using noneconomic data. One example of the application of the equity measures to noneconomic data relates to the changes in the distribution of emission of pollutants over the area of study. It might even be feasible to evaluate the changes as they occur between and within segments of the population. The segments can be defined relative to the socioeconomic characteristics of the population or by locations in the study area. A decomposable measure is necessary for this purpose (*8, 14*).

The incidence of net efficiency gains of a transportation 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 transportation market and the rest of the economy, especially the labor 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 measures of accessibility to obtain some indication of the distribution of the incidence of the net benefits. Equity and accessibility measures suggest only the likely direction of impacts and should be treated as such. The ex post analysis of equity provides some information on how to recycle revenues to address equity considerations.

TABLE 1 Properties of Inequality Measures

Measure	Definition	Properties: Transfer	Scale Invariance	Translation Invariance
Range	$R = Y_{\max} - Y_{\min}$			
Variance	$V = \frac{1}{n}\sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)^2$	Yes	No	Yes
Coefficient of variation	$c = \frac{\sqrt{V}}{\bar{Y}}$	Yes (weak)	Yes	No
Relative mean deviation	$M = \frac{1}{n}\sum_{i=1}^{n}\left\lvert\frac{Y_i}{\bar{Y}} - 1\right\rvert$	Yes	Yes	No
Logarithmic variance	$v = \frac{1}{n}\sum_{i=1}^{n}\left(\log\frac{Y_i}{\bar{Y}}\right)^2$	No	Yes	No
Variance of logarithms	$v_1 = \frac{1}{n}\sum_{i=1}^{n}\left(\log\frac{Y_i}{\bar{Y}_{\log}}\right)^2$	No	Yes	No
Gini	$G = \frac{1}{2n^2.\bar{Y}}\sum_{i=1}^{n}\sum_{j=1}^{n}\lvert Y_i - Y_j\rvert$	Yes (weak)	Yes	No
Theil's entropy	$T = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{Y_i}{\bar{Y}}\right)\log\left(\frac{Y_i}{\bar{Y}}\right)$	Yes	Yes	No
Atkinson	$A_\epsilon = 1 - \left[\frac{1}{N}\sum_{i=1}^{N}\left(\frac{Y_i}{\bar{Y}}\right)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}$	Yes	Yes	No
Kolm	$K_\alpha = \frac{1}{\alpha}\log\left\{\frac{1}{N}\sum_{i=1}^{N}\exp\left[\alpha\left(\bar{Y} - Y_i\right)\right]\right\}$	Yes	No	Yes

Some Accessibility Measures

Two alternative approaches were to measure accessibility. [A review of accessibility measures is available elsewhere (*15* and *16*).]

The gravity or opportunities approach is defined by

$$G_i = \sum_{j\in L}\frac{W_j}{f\left(c_{ij},\beta\right)} \tag{1}$$

where

W_j = mass of opportunities available to i at location j,
$f(c_{ij},\beta)$ = deterrence function = $f(c_{ij},\beta) = e^{\beta c ij}$,
β = a constant assumed to equal to 0.35, and
c_{ij} = generalized cost of travel by car between i and j.

Four alternative accessibility measures are constructed through use of 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 to 65 years of age at j, and
- G_W, in which W_j is equal to the female population at j.

Logsum measure is defined as

$$\log\text{sum}_i^n = \max_{i,\,j\in L} U_{j|i}^n = \frac{1}{\mu}\ln\sum_{j\in L}\exp\left[\mu\left(v_j^n - c_{ij}^n\right)\right] \tag{2}$$

where

logsum_i^n = measure of accessibility at location i for individual n,
$U_{j|i}^n$ = utility of travel to location j given the individual n is located at i,
v_j^n = attraction at j,
c_{ij}^n = travel cost between i and j, and
μ = positive scale parameter that is estimated.

This class of measures has its roots in the application of random utility maximization (RUM) for travel demand modeling. It is common to refer to the unknown in Equation 2 as "logsum." The advantages of this approach are its underpinning behavioral theory and the fact that accessibility is linked to the consumer welfare measure and that it can be expressed in monetary terms (*17, 18*). The above formula is valid if the nonpresence of the income effect is assumed. McFadden (*19*) provides both an overview of recent developments in RUM and alternative approaches for the calculation of a "correct" welfare measure in the presence on income effect. Among these approaches is a closed formulation derived by Karlström (*20*).

PERFORMANCE OF EQUITY MEASURES

Characteristics of Case Studies

The greater Oslo, Norway, area has a population of about 1 million and an area of 5,305 km^2. The population density is about 140 inhabitants per square kilometer. Oslo city has a population of about 512,000. 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 about €1.14 billion (2002 euros), approximately 15% to 20% above the initial estimate. In 2000, the Parliament approved an increase in the toll fee to finance an investment package on public transportation projects, referred to as Oslo Package 2 (*21*).

There is much debate and some interest in changing the direction of the scheme to a congestion pricing scheme beginning in 2008. Equity has been an important concern in the debate on the new package. Among the different alternatives that have been evaluated for Oslo is a time-differentiated toll scheme. Revenues will be allocated to public transportation 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.

The following sections evaluate the performances of equity measures in two case studies for Oslo. The instruments, their levels, and the packages used in the 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.

Framework for Evaluation

A multimodal transportation model RETRO is used in this study (*22*). RETRO has the following submodels:

1. Disaggregate and aggregate license-holding models,
2. Disaggregate car ownership models,
3. Disaggregate models for travel frequency and models for mode and destination choices,
4. Segmentation model, and
5. 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 relative to an objective function (OF) that accounts for the net benefits of all the affected actors, users (consumer surplus), producers (producer surplus), government (government surplus), and nonusers (environmental effects and accident), defined as

$$\mathrm{OF} = \sum_{t \in t^*} \frac{1}{(1+r)^t} \left(\mathrm{CS}_t + \mathrm{PC}_t + \mathrm{MCF}_t * \mathrm{GS}_t + \mathrm{env}_t + \gamma_t g_t \right) \qquad (3)$$

where

OF = net benefit,
t^* = horizon year,
r = discount rate,
CS_t = change in consumer surplus in year t,
PS_t = change in producer surplus in year t,
GS_t = change in government surplus in year t,
MCF_t = marginal cost of public funds in year t,
env_t = external costs defined as accident, noise, and pollution costs and other external effects in year t,
γ_t = shadow cost of CO_2 emissions, reflecting national CO_2 target for year t, and
g_t = 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 transportation operators. The tax revenue associated with car use and car ownership is included in the government surplus.

First Case Study for Oslo

The first case study is taken from the AFFORD project (*23*). In this project, a number of packages of instruments are calculated to maximize the objective function described by Equation 3. For the purpose of this study, the package composed of a time-differentiated toll ring scheme and time-differentiated parking fees is selected (Scenario P21). The toll fee in this scenario is about €2.7 during peak periods and no charge off peak. The parking fee is slightly higher during peak periods (1.025 times the present levels) and slightly lower off peak (0.996 times the present levels). This is called the policy scenario, which is calculated under alternative assumptions about the recycling schemes: no recycling, a flat recycling, and a proportional recycling of the revenue among households. The public treasury keeps the generated revenue 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., given percentage of income tax relief). Table 2 shows the income distributions in the reference scenario and in the policy scenario under alternative assumptions about the recycling of the revenue. Figure 1 shows the changes in income in the policy scenario compared with those in the reference scenario for the eight income groups.

TABLE 2 Income Distribution in Alternative Scenarios

Income Group	Income–Consumption Unit (euros/year) Reference	No Recycling	Flat Recycling	Proportional Recycling
1	1,736	1,719	1,801	1,726
2	7,617	7,593	7,653	7,625
3	11,369	11,329	11,398	11,377
4	14,830	14,778	14,846	14,841
5	18,024	17,966	18,035	18,042
6	21,164	21,097	21,166	21,187
7	25,347	25,275	25,339	25,382
8	41,806	41,723	41,787	41,901

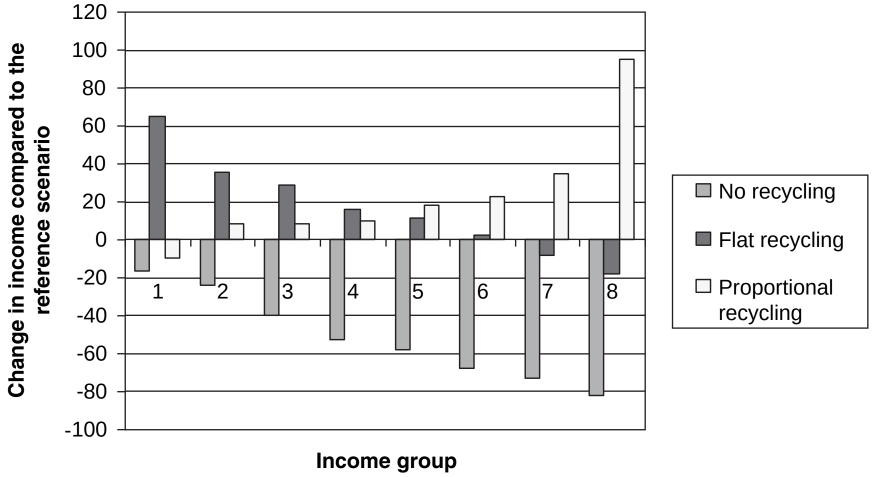

FIGURE 1 Changes in income in policy scenarios compared with reference scenarios.

Figure 1 also shows that the average income of all income groups decreases in the policy scenario with no recycling. However, the low-income groups lose less in proportion to their incomes than the high-income groups. A flat-recycling scheme favors the low-income groups. And a proportional-recycling scheme favors high-income groups. Hence, the sets of weights that are attached to transfers at various points in a distribution are different among these scenarios.

Table 3 shows the performances of the equity measures described earlier when applied to the income distributions shown in Table 2. The scale of income is quite important in a number of these measures. Furthermore, the relationship between the aversion parameters in the Kolm and Atkinson measures can be established by setting the elasticity of marginal utility of income derived from the Atkinson social welfare function equal to that from the Kolm social welfare function, as follows:

$$\alpha = \epsilon / \overline{Y} \tag{4}$$

A first task is to compare the performances of these measures for the reference scenario and the policy scenario with no recycling. As

TABLE 3 Performances of Equity Measures

	Scenario			
Equity Measure	Reference	No Recycling	Flat Recycling	Proportional Recycling
Mean	17,737	17,685	17,753	17,760
Range $Y_{\max} - Y_{\min}$	40,070	40,004	39,987	40,175
Variance	132,062,507	131,596,975	131,533,921	132,719,502
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
Gini	0.353895	0.354231	0.352785	0.354230
Atkinson				
$\epsilon = 0.2$	0.04472	0.04482	0.04433	0.04482
$\epsilon = 0.5$	0.11774	0.11802	0.11652	0.11802
$\epsilon = 1.5$	0.41511	0.41642	0.40845	0.41641
$\epsilon = 3$	0.73744	0.73904	0.72883	0.73903
$\epsilon = 5$	0.83556	0.83666	0.82960	0.83666
$\epsilon = 10$	0.87670	0.87753	0.87221	0.87753
Kolm				
$\alpha = 0.2/\overline{Y}$	291.46168	312.79678	282.95226	282.69548
$\alpha = 0.5/\overline{Y}$	724.29198	744.05323	713.97733	717.41044
$\alpha = 1.5/\overline{Y}$	1,887.99309	1,903.44023	1,872.56346	1,885.12111
$\alpha = 3/\overline{Y}$	3,096.07909	3,107.38008	3,075.22532	3,096.25462
$\alpha = 5/\overline{Y}$	4,129.87551	4,138.63246	4,105.05517	4,132.09095
$\alpha = 10/\overline{Y}$	5,360.35657	5,367.77234	5,332.70264	5,364.10460

TABLE 4 Differences Between Accessibility Measures in Policy and Reference Scenarios

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

Figure 1 shows, while all income groups lose in the policy scenario without recycling, the low-income groups lose less in proportion to their incomes than the high-income groups. These shifts in income distributions are reflected by the measure used. Mean, coefficient of variation, relative mean deviation, logarithmic variance, the Gini coefficient, the Theil measure, and Atkinson measures for different aversion parameters suggest that the policy scenario with no recycling has worsened the income distribution. Range, variance, and variance of logarithms suggest that the policy scenario with no recycling improves the income distribution.

The results also suggest that the policy scenario with a flat recycling scheme produces a more desired income distribution than the reference scenario according to all measures, including the Gini coefficient, except for the variance of logarithms and the Atkinson and Kolm measures for all the examined aversion parameters. The ranking between the policy scenario without recycling and the policy scenario with proportional-recycling scheme according to the Kolm measure is sensitive to the aversion parameter.

Mean, variance of logarithms, and the Atkinson and Kolm measures for all the examined aversion parameters rank the income distribution in the policy scenario with proportional-recycling scheme the best, while other measures (range, coefficient of variation, relative mean variation, logarithmic variance, the Theil measure, and the Gini coefficient) rank the policy scenario with a flat-recycling scheme the best. An exception is the Kolm measure, with an aversion parameter of $0.2/\bar{Y}$.

This exercise illustrates that different measures of equity produce different rankings of the distributions of incomes. The income distributions in these scenarios obey the Lorenz dominance axiom (*23*), and hence one would have hoped that all measures of inequality agree on ranking (*13*). In this case, they do not. Consequently, it is imperative that a number of equity measures that capture differences in normative positions of a society be employed rather than a single measure.

Second Case Study for Oslo

The second case study is taken from the SPECTRUM project (*24*). The objective function described by Equation 3 is used to evaluate a reference scenario and a number of packages of instruments for Oslo. The package of instruments comprising a time-differentiated toll ring scheme (about €4.38 during the peak periods and about €1.75 off peak), an increase in fuel taxes by 50%, and an increase in public transportation frequency of services by 5.8% is selected for this study.

Table 4 shows the differences between the accessibility measures in the policy and the reference scenarios. Figure 2 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 dramatically decrease accessibility by car (G_Emp, G_W, G_65+, and G_20−65). The 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 acces-

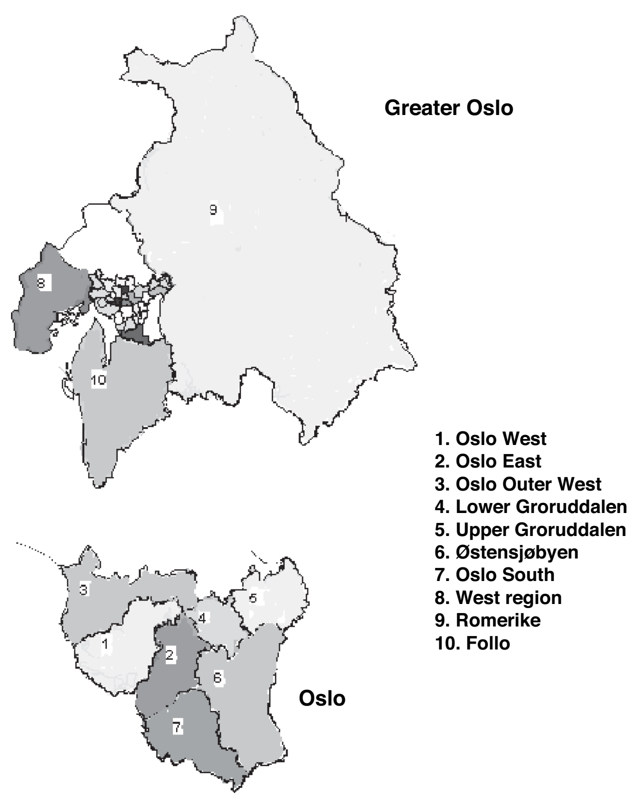

FIGURE 2 Greater Oslo area.

sibility to the employment in different locations. All these measures have similar patterns. They all indicate that, for all segments of the population, the accessibility by car to Upper Groruddalen will decrease most. Accessibility for employment (G_Emp) and accessibility for the population of aged 20 to 65 (G_20–65) have similar patterns.

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 public transportation services. This measure also 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 earlier are used. Table 5 shows a summary of some of these inequality measures applied to the geographical distributions of welfare over 49 zones that represent 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 the reference scenario than in the policy scenario.

Table 6 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 4 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 that most measures are quite similar in both scenarios and that the geographical distribution of welfare is more even in the reference scenario than in the policy scenario. Table 5 also shows the sensitivity of the Atkinson and Kolm measures to the inequality aversion parameter. The Atkinson measure is more sensitive than the Kolm measure to the value of the inequality aversion parameter.

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 4 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/year for an average traveler. Yet the sizes of the different equity measures (see Tables 5 and 6) vary significantly as the result of the level of spatial disaggregation in the measure of welfare. Similarly, some of the measures are quite sensitive to the scale of the welfare measure. This study illustrates that relating the equity objective to a predefined value on any of these measures is not a desirable approach. Furthermore, it is difficult to make a judgment 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.

TABLE 5 Summary of Inequality Measures in Alternative Scenarios (49 zones)

49 Zones	Policy Scenario	Reference Scenario
Mean	498.35	504.89
Range $Y_{max} - Y_{min}$	360.67	361.56
Variance	5,175.71	5,072.69
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 6 Summary of Inequality Measures in Alternative Scenarios (10 zones)

10 Zones	Reference Scenario	Policy Scenario
Mean	525.29	519.09
Range $Y_{max} - Y_{min}$	113.01	115.20
Variance	1,710.49	1,714.08
Coefficient of variation	0.0787	0.0798
Relative mean deviation	0.0697	0.0703
Logarithmic variance	0.0013	0.0013
Variance of logarithms	5.2205	5.2007
Theil	0.0013	0.0014
Gini	0.04118	0.04199
Atkinson		
$\epsilon = 0.0001$	0.0000003	0.0000003
$\epsilon = 0.001$	0.0000032	0.0000033
$\epsilon = 0.005$	0.0000616	0.0000163
$\epsilon = 0.01$	0.0001260	0.0000326
Kolm		
$\alpha = 0.0001$	0.0372	0.0373
$\alpha = 0.001$	0.3757	0.3765
$\alpha = 0.005$	1.9563	1.9607
$\alpha = 0.01$	4.0663	4.0774

SOME CONCLUSIONS

Partial equilibrium models of transportation or integrated transportation and land use models are the most commonly used planning tools for the evaluation of the impacts of transportation 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 was to illustrate some important issues related to the evaluation of equity through use of a partial equilibrium model of transportation, with examples from Oslo. Equity and accessibility measures provide information about the potential distribution of welfare among a population or over a geographical area.

This paper illustrated that the equity implication of any of the policy scenarios depends on the normative positions and the perception of inequality. Consequently, it is imperative that the evaluation of the equity implications of a transportation policy employ a number of equity measures that capture differences in normative positions of a society rather than a single measure.

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 judgment about the equity implication of a policy on the basis of a single measure and without a thorough examination of several measures.

This exercise relies on a partial equilibrium transportation model and the ex post evaluation of the equity implications of a package of instruments. Nonetheless, the lessons can be extended to a general equilibrium approach in which an explicit form of social welfare function and an inequality aversion parameter are used to address equity concerns.

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.

REFERENCES

1. Sandmo, A. *The Public Economics of the Environment.* Oxford University Press, Oxford, United Kingdom, 2000.
2. Sen, A. K. *Choice, Welfare and Measurement.* Harvard University Press, Cambridge, Mass., 1982.
3. Sen, A. K. *Inequality Reexamined.* Oxford University Press, Oxford, United Kingdom, 1992.
4. Kolm, S.-C. The Optimal Production of Social Justice. In *Public Economics* (J. Margolis, and H. Guitton eds.), Macmillan, London, 1969.
5. Atkinson, A. B. On the Measurement of Inequality. *Journal of Economic Theory,* Vol. 2, 1970, pp. 244–263.
6. Sen, A. K. *On Economic Inequality.* Oxford University Press, Oxford, United Kingdom, 1973.
7. Harrison, E., and C. Seidl. Acceptance of Distributional Axioms: Experimental Findings. In *Models and Measurement of Welfare and Inequality* (W. Eichhorn, ed.), Springer–Verlag, New York, 1994, pp. 67–94.
8. Myles, G. D. *Public Economics.* Cambridge University Press, Cambridge, United Kingdom, 2000.
9. Pigou, A. C. *The Economics of Welfare,* 4th ed. Macmillan, London, 1954.
10. Dalton, H. The Measurement of the Inequality of Incomes. *Economic Journal,* Vol. 30, 1920, pp. 348–361.
11. Kolm, S.-C. Unequal Inequalities I. *Journal of Economic Theory,* Vol. 12, 1976, pp. 416–442.
12. Kolm, S.-C. Unequal Inequalities II. *Journal of Economic Theory,* Vol. 13, 1976, pp. 82–111.
13. Shorrocks, A., and D. Slottje. Approximating Unanimity Orderings: An Application to Lorenz Dominance. In Inequality Theory, Experiments and Application (P. Moyes, C. Seidl, and A. Shorrocks, eds.), *Journal of Economics,* Supplement 9. Springer, New York, 2002, pp. 91–117.
14. Cowell, F. A. *Measuring Inequality,* Philip Allan, Oxford, United Kingdom, 1977.
15. Geurs, K. T., and J. R. Ritsema van Eck. *Accessibility Measures: Review and Applications.* RIVM Report 408505 006. National Institute of Public Health and the Environment, Bilthoven, Netherlands, 2001.
16. Baradaran, S., and F. Ramjerdi. Performance of Accessibility Measures in Europe, *Journal of Transportation and Statistics,* Vol. 4, No. 2–3, 2002, pp. 31–48.
17. Ben-Akiva, M., and S. R. Lerman. Disaggregate Travel and Mobility Choice Models and Measures of Accessibility. In *Behavioural Travel Modelling* (D. Hensher and P. R. Stopher, eds.), Croom Helm, London, 1979.
18. Williams, H. C. W. L. On the Formulation of Travel Demand Models and Economic Evaluation Measures of User Benefits. *Environment and Planning.* Vol. A 9, 1977, pp. 285–344.
19. McFadden, D. Disaggregate Behavioural Travel Demand's RUM Side. In *The Leading Edge of Travel Behaviour Research* (D. Hensher, ed.), Pergamon Press, Oxford, United Kingdom, 2001.
20. Karlström, A. *Four Essays on Spatial Modelling and Welfare Analysis.* TRITA-IP FR 99-49. Department of Infrastructure and Planning, Royal Institute of Technology, Stockholm, Sweden, 1999.
21. Ramjerdi, F., H. Minken and K. Østmoe. The Norwegian Urban Tolls. In *Road Pricing: Theory and Practice* (G. Santos, ed.), Elsevier, London, 2004.
22. Ramjerdi, F., and A. Rand. National Forecasting Model System for the Evaluation of the Impacts of Alternative Policy Measures on Transportation and Environment. In *Modelling the Economy and the Environment* (B. Madsen, C. N. Jensen-Butler, J. B. Mortensen, and A. M. B. Christensen, eds.), Springer–Verlag, Berlin, 1996.
23. Fridstrøm, L., H. Minken, P. Moilanen, S. P. Shepherd, and A. Vold. *Economic and Equity Effects of Marginal Cost Pricing in Transportation.* VATT Research Report 71, Helsinki, Finland, 2000.
24. Ramjerdi, F., K. Østmoe, and H. Minken. Experience with Measuring Equity and Efficiency: A Case from Oslo. In *Road Pricing, the Economy, and the Environment,* Springer–Verlag, Berlin, in press.

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