Modelling effects of policy instruments for sustainable urban transport in Scandinavia

Roger Pyddoke – VTI

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Abstract

The purpose of this paper is to review the modelling used for the planning of infrastructure and design of policy instruments for transport in cities in Scandinavia, and to survey elasticities of transport demand with respect to policy instruments and important background variables. There are a number important objectives governing policy, maximizing welfare, reducing CO_2 and other emissions, curbing congestion on roads and crowding in public transport in cities and improving the conditions for walking and cycling. The current transport demand models in Sweden and Norway were originally built to serve the purpose of forecasting for national infrastructure planning, primarily outside cities. They were not designed to represent the adaption of car use, congestion on roads or crowding in public transport or the effects of improving of conditions for walking and cycling. Therefore, recent discussions on the needs to develop planning for cities has raised these issues.

The central results from the survey of effects are that, car use is shown to be more price sensitive in urban than in rural areas, and larger the larger the city. Although the benefits of a given congestion charging system are considerably and non-linearly dependent on initial congestion levels, traffic effects and adaptation costs are surprisingly stable across transport system modifications. The demand for car travel is largely insensitive to supply of public transport and

Centre for Transport Studies
SE-100 44 Stockholm
Sweden
www.cts.kth.se

on baseline congestion, and therefore on the total benefit of the charges. For public transport both population size and population density appear to independently influence public transport use. The estimated elasticities being 0,48 and 0,17 respectively. What is not obvious is when supply could improve net welfare. Both an increase in the population and the following crowding can motivate an increase in frequency by the increased net welfare.
Large dense cities with more public transport are found to have less car use. The form of the city and its long time use of strategies to facilitate public transport use also decreases the market share of car travel and increases the share of public transport. In large cities density is also found to be correlated with less car and energy use in many cross-sectional studies. The idea that density could induce less car use and CO_2-emissions is however challenged by a smaller number of longitudinal studies showing smaller effects from density to car use and CO_2-emissions. It has been suggested that some of the effects found in cross sectional studies may not remain in before and after studies. Even though land use policies can be beneficial, their effects are generally less well known than policies addressing transport congestion externalities. As these are better known and likely to be welfare improving the effects of policy instruments associated with congestion pricing, parking pricing, improvements of the supply of public transport are likely to be preferable.

Keywords: Sustainable, Urban Transport, Policy instrument, Car, Public transport, Congestion, Crowding, Parking, Density,

JEL Codes: R48, R52

These can be found at:
http://www.aeaweb.org/jel/jel_class_system.php#Y

1 INTRODUCTION

A point of departure for this paper is the observation that increasing populations and increased car use are challenges facing policymakers in cities all over the world. This requires attention in terms of long term decisions on how to plan cities and provide transport. The objective here is to survey results relevant for primarily the planning of land use and transport in cities[1]. The paper surveys models of policy instruments for urban transport and land use with the aim of supporting policy decisions to achieve higher degrees of sustainability. The objective of sustainability covers several dimensions today. In the context of transport sustainability, it is strongly associated with less greenhouse gas emissions. This is frequently assumed to imply a need for radical reductions of the use of private cars and increases in the supply of public transport. Economic sustainability can also be interpreted in terms of an acceptable rate of growth, allowing for new social needs to be fulfilled. This goal will imply a high priority for economic efficiency. Social sustainability entails a community where all citizens can reach gainful employment, social and commercial services. This also reflects a distributional objective, in the sense that if markets do not spontaneously deliver a fair distribution of living standards and transport services then policy measures will be required.

The policy instruments considered in this study are primarily those applied by cities or states and directed at greenhouse gas emissions, congestion on roads, crowding in public transport and land use. Mainly because both Norway and the Sweden as well as local political assemblies have set ambitious objectives for the reduction of greenhouse gas emissions from the transport sector and for transport in urban areas. In 2012 the Norwegian government (Meld.St. 21 (2011-2012) set the goal that car transport in Norwegian cities should not grow and that all transport growth should be served by public transport or walking and cycling. Recently Swedish parliament increased the ambitions by setting the national objective for transport in Sweden to be fossil free by 2045 (all seven parliamentary parties in the commission for new climate goals in SOU 2016:21). In 2008 many Swedish regional public transport authorities adopted the goal to double travel with public transport to 2020 and market share to 2030 both compared to 2006. And, in addition, cities purchase carbon free buses. The search was directed towards planning regulations, pricing/taxes, design and magnitude of public transport supply. Many published analyses on transport in urban areas however disregard national policies, e.g. fuel taxes, subsidies to environmentally friendlier cars and national infrastructure priorities.

Nevertheless, national policies may have considerable future effects, in particular, if Norway and Sweden decide to pursue ambitious national targets for reduction of greenhouse gas emissions. This could then include increased fuels taxes, increased vehicle taxes, subsidies for cars with small or no emissions. In scenarios with more electric cars, the emissions would be significantly reduced

[1] This paper is developed as a deliverable with the VINNOVA financed project Sustainable public transport in cities. The overarching objective of the project is to develop and apply a policy model (the HUT-model) developed for Norwegian and Swedish cites with the purpose of demonstrating effects of supplying road infrastructure, public transport or walking and cycling and using policy instruments like public transport supply, parking charges and land use policies for cities in these two countries.

and the greenhouse gas justification for public transport improvements would diminish. Policy instruments directed at congestion in city streets could still be justified in such a scenario. Using policies to reduce congestion will shift demand towards public transport and walking and cycling. In this context a welfare economic justification for subsidies of public transport would have to rely more on savings in travel time, delay time and valuation of less crowding. In addition, positive effects for underprivileged groups could be valued higher than their willingness to pay. The important conclusion is that national policies change the preconditions for reaching both congestion and greenhouse gas emission reductions in cities. These objectives may even in some cases be reached solely by a cost minimizing adaption to national policy instruments and without further ambitions added from the region or municipality.

1.1 The current national demand models and their use in planning

In Norway and Sweden there is an extensive use of national large scale transport demand models for policy modeling[2], of a “nested logit model type”, the RTM-model (Regionale Transport Modellene) in Norway and the SAMPERS model in Sweden (and its simplified variant - LUTRANS). Both countries also use freight transport demand models representing the freight transport buyer’s choices of logistic solutions.

For long term planning the models are used to forecast the development of transport demand given exogenous macroeconomic growth, industry growth, demographic development and localization of residences and workplaces. The supply of infrastructure and of public transport are taken as given and are not modeled as endogenous.

The use of these models was initially mostly for the national planning of infrastructure but was soon extended to land use and policy instruments (se Jonsson et al. 2011 for a presentation of the use of SAMPERS in Swedish planning). An important component of the current model (-s at least in Sweden) is that they are appended with cost-benefit analysis calculation systems which receive data from the demand calculations and uses nationally determined calculation prices. This means that many policy scenarios, e.g. taxation on fuel and congestion and subsidized public transport fares, can be evaluated in terms of consumer surpluses (social welfare). Some dimensions are however not covered with current versions.

A plausible reason for the relative success of the planning paradigm using large scale demand modeling is the projection of accurate prediction of transport flows. In important cases the models also suggest consequences that would otherwise be hard to foresee (Jonsson et al. 2011), e.g. traffic flows in networks.

At the same time much of the debate on these models concern the possibility to make the results more resolved and to account for more complex situations (e.g.

[2] Estrada (2011 p 524) defines “policy modeling” as “an academic or empirical research work, that is supported by the use of different theories as well as quantitative or qualitative models and techniques, to analytically evaluate the past (causes) and future (effects) of any policy on society, anywhere and anytime.” As an integral part of this definition, “policy” is defined as “a theoretical or technical instrument that is formulated to solve specific problems affecting, directly or indirectly, societies across different periods of times and geographical spaces.” Estrada (2011 p 524)

Tørset et al. 2011 and Fearnley et al. 2015). According to Trafikverket[3] (2015) the current models are, however, not built to fully represent congestion on roads in urban areas, crowding in public transport or delays from many passenger boarding and alighting at bus stops. Neither do they represent the benefits of improved cycle infrastructure, coordinated timetables and parking supply and pricing. Furthermore, the significant interdependencies between land use and transport demand is only partially dealt with in current planning practices (Trafikverket 2015).

These limitations are not necessarily limiting when it comes to many national infrastructure projects as these are frequently outside urban areas. In the case of projects to be built in urban areas, however, these considerations are likely to weigh heavier. The reason is that population and income growth both contribute to scarcity of space for infrastructure which has generated a scarcity of capacity for roads, public transport as well as an underestimation of the demand effects from improving public transport services or bicycle infrastructure.

But even though these models allow for high degrees of resolution outside urban areas (and not so high in urban areas that may be developed even further in the future) this resolution comes at a price in terms of limitations and costs for analyzing the results.

So far the Swedish SAMPERS system has also been hampered by long execution times. This led to the development of a faster version called LUTRANS. The costs for updating and revising the representation of road net, public transport supply and the relationships representing accidents, air pollution, noise etc. have also led to delays in updating and implementation of new relationships.

Jonsson et al. (2011) conclude that certain types of development are desirable. Models should enable more interactive use and therefore allow for turnaround times to be improved. Models should also be flexible not only by allowing for more policy alternatives but also allowing for new dimensions and assumptions and for behavior to vary as well. An example of a new dimension could be cost assessments for expanding infrastructure and public transport supply. It is also desirable to use quicker, less detailed models in early stages when many options are explored and a more detailed when a full CBA is to be calculated. The authors even suggest that "it may actually be better … to give up the ambition to be accurate and instead view strategic modelling as a way of telling internally consistent stories". They hasten to emphasize that in other contexts a higher accuracy may well be desirable.

1.2 The needs in urban planning - a model for strategic urban transport policy analysis

We turn now to urban planning. Preparing decisions on land use, infrastructure and public transport supply requires costly design work and cost calculations. This raises the question of the need to develop simplified models for representing costs for infrastructure and public transport rolling stock and services. The objective of such models is essentially to represent the consequences of providing

[3] The Swedish Transport Administration is the Swedish national agency responsible for planning transport infrastructure.

transport by different modes simultaneously with variations in other policy instruments like road pricing and public transport pricing as well as land use planning policies directed at increasing density.

The present state-of-art versions of the transport demand models may mostly be considered as capable of predicting traffic flows on infrastructure (Almroth et al. 2014). As mentioned above the models are not built to represent all dimensions. To evaluate packages of policies both the effects of individual instruments and packages should ideally be modelled as endogenous. This implies modelling any supply and price changes occurring as a response to policy changes. A reference scenario, without policy changes, is also needed to determine the effects of individual instruments and packages. A full cost-benefit analysis would require modelling all relevant external effects and the changes in car and public transport use. Such an analysis should include welfare losses due to pricing and un-priced externalities. If possible such models could also include long run dynamic effects, in the sense of adaptions requiring investment in new infrastructure, vehicles or moving residence and the place of employment, implying changes in land use. At present such all-encompassing planning tools do not exist, and civil servants must therefore settle for using existing tools. This implies making simplified assumptions on supply and pricing responses from operators and citizens.

This remainder of this paper is structured as follows. In Section 2 some general equilibrium modeling approaches with results from Sweden are presented. Section 3 discusses general theories of optimal land use and policy instruments in cities. Section 4 presents an introductory discussion to elasticity estimates and presents the influence of selected policy instruments on car use. Section 5 presents the effects of public transport parameters, variables exogenous to the public transport operator and other policy instruments on public transport demand. Section 6 reviews results suggesting that the density and form of city influences car use and CO_2-emissions. Section 7 Presents the central observations creating doubts on the possibility of using policies to densify cities to reduce car use and CO_2-emissions. Section 8 discusses the central findings. Section 9 concludes.

2 TRANSPORT AND CO_2-EMISSIONS IN A GENERAL EQUILIBRIUM MODEL

2.1 A national policy model covering transport - The Swedish EMEC model

The Swedish National Institute of Economic Research (Konjunkturinstitutet) has developed a calculable general equilibrium model, EMEC, primarily for the study of energy consumption and environmental development. The purpose is to do aggregate analysis of energy and environment policy. The model can also be used to calculate consistent macroeconomic scenarios or the development of different sectors in the economy. Corresponding models and calculations are provided by Miljødirektoratet (2014) for Norway and Energistyrelsen (2013) for Denmark.

A Report from 2013 Konjunkturinstitutet analyses three policy scenarios for reducing greenhouse gas emissions. The first scenario, the reference scenario, implies a policy accommodating for EU requirements. This scenario is reached by policies suggested by EU, and assumes an objective of 80 percent reduction of emissions to 2050. Also assuming a continuous decrease an implicit reduction objective for 2030 can be calculated. Calculations by the IEA (2013) also indicate that emissions in the transport sector can decrease by 80 percent to 2050. The second scenario assumes policies to induce a development of technology leading to less emitting road vehicles. The third scenario in addition to the development of emitting technology also assumes city planning to adapt to more compact urban areas. The two latter scenarios are calculated to reach further reductions than the EU requirements.

In the reference scenario, taxes except for energy and carbon taxes, are assumed to be unchanged. The budgets are modelled to be in balance. The macroeconomic development is highly determined by the demographic development which is assumed to follow the forecast by Statistics Sweden. Note that this forecast can, but is not generally broken down to a highly geographically resolved level. The labor market in the sense of employment rate and the number of hours worked is also assumed to be unchanged. The long run development of productivity growth is assumed to be the same as the average the last thirty years. The relative growth and productivity growth in different sectors is uncertain which also potentially impacts employment. This development in turn strongly determines future emissions of carbon.

The share of current (60 percent of the emissions outside the trading system EU ETS in 2010) and future emissions expected to emanate from transport makes this the largest challenge for reaching the high objectives of the Swedish government.

The *necessary developments* for the transport sector envisaged by Trafikverket (2012) include a more energy efficient car fleet to 2030 (reducing energy consumption by 50 percent), 20 percent of cars being electric and the use of biofuels doubling. Furthermore, Trafikverket (2012) assumes that the total number of vehicle kilometers traveled will decrease by 20 percent from 2010 to 2030.

Konjunkturinstitutet (2013) remark that Trafikverket (2012) largely remains silent on the necessary policy instruments that will be needed to reach these objectives. One of the policies that has been suggested to contribute to the attainment of these goals has been a massive increase of the supply of public transport. On this Konjunkturinstitutet (2013) refers to Nilsson, Pyddoke and Andersson (2013) who state that even a doubling of public transport trips would have only modest effects on carbon emissions.

Konjunkturinstitutet (2013) proceeds to examine a combination of a CO_2 tax and a regulation on CO_2-emissions from cars. They present calculations suggesting that CO_2 taxes must increase in the order of magnitude of 900 percent in order to reach the goal of reduction. The social welfare costs of decreasing CO_2-emissions are approximated by the reduction in GDP. These calculations suggest that in a combination with a regulation of emission maximum of 65 grams per kilometer the objective of Scenario 2 can be achieved at a cost of a GDP reduction of 1 percent. For Scenario 1 further tax-increases are required leading to calculated GDP reductions of circa 5 percent. These calculations are supplemented with the caveat that a price increase for fuel will trigger further adaptions in the car fleet that are not covered in the calculation. At the same time the costs of adapting the car fleet are not included. Also the increase in fuel efficiency is likely to lead to a rebound effect in the sense that increased fuel efficiency will lead to reduced costs for driving which in turn can lead to an increase in car use. Ultimately this leads up to the conclusion that reducing CO_2-emissions from transport will only come at a considerable cost.

3 WHAT IS WELFARE OPTIMAL STRUCTURE AND POLICY FOR CITIES?

Economic theory provides tools for evaluating policies from the perspective of individual willingness to pay. In principle this approach could cover all effects on individual welfare and all kinds of preferences including individual preferences for distribution of welfare. In practice, however, cost-benefit analyses take only limited account of potential preferences. They focus on individual welfare and externalities but not on preferences politics and redistribution. Planners tend to focus on what they generally assess to be the most important direct effects of policies. In many policy cases distributional effects are therefore not analyzed.
In a much cited paper Anas Arnott and Small (1998) summarize the implications of optimal city structure for policy. Starting from a monocentric city, which is efficient, they emphasize that it is not in the presence of externalities. In the last part of the paper they focus on congestion externality. This arises as car drivers do not pay for their marginal contribution to congestion. This causes rent and density functions to be flatter and the city to be larger than without congestion. This excessive decentralization encourages planners to allocate too much land to roads. With unpriced congestion, prices for land at central locations is less than its shadow value.
But although agglomeration economies are the *raison d'être* for cities, the exact relationship is not well known.

> Broadly speaking, then, we are confronted with a situation with three classes of externalities
> transport congestion externalities, neighborhood externalities, and agglomeration externalities. We understand the first two classes much better than the third, although the third is probably the most important. Under these circumstances, theory provides only limited guidance concerning optimal policy. Our judgment is that piecemeal second-best policies addressing just transport congestion externalities are likely to be welfare improving. Such policies include congestion pricing, parking, pricing, some measures to encourage carpools, and restricting road capacities in central areas. Land use controls can sometimes be beneficial, but are more problematic because they tend to repress market forces. (Anas et al. 1998)

A more recent survey (Gyourko and Molloy 2015) the authors argue that the effects of housing regulation is still not fully understood.

> It is not obvious that regulation should reduce welfare, even if it raises housing costs, because many forms of regulation are designed to generate local amenities or mitigate negative externalities. However, most theoretical and empirical research has found that the costs of regulation outweigh the benefits by a substantial margin. Given this result, it might be somewhat puzzling that land use regulations are so ubiquitous. One possibility is that agents who do benefit from regulation have more influence in the local political process, leading to a result that benefits a few at the expense of the majority. Another possibility is that local policy makers and their constituents have an inflated view of the benefits or underestimate the costs. (Gyourko and Molloy 2015)

The conclusion then is to be wary against far reaching land use policies as the full consequences of such policies are not well known.

4 CAR OWNERSHIP AND CAR USE

The demand elasticities reported in this and the following section are, unless otherwise mentioned, primarily short run elasticities. They may, however, to varying degrees be a mixture between the immediate short-run impacts of a change in a policy variable, like frequency, and more long run effects including effects of various adaptions of further policy variables and the corresponding behavioral adaptions. When estimating long run effects econometrically there will be a limited number of control variables. If therefore the estimation of the elasticity of demand with respect to a variable, does not control for relevant adjustments in other policy variables, the long run elasticity will therefore contain effects of adaptions in the uncontrolled policy variables.

In many cases the full adaptions may not be automatically represented. Consider the following example, the public transport provider, reduces all fares. This will increase demand. As supply is not modelled as endogenous, adjustments are likely to have to be made in the supply, like an increased number of departures. If the modeler takes the time to do these adjustments a higher level of demand will be reached. Thus, many changes in policy variables for which elasticities are presented in this paper are likely to require adjustments of other policy variables. Consider one further example. The Swedish and Norwegian national demand models represent a base line supply of road infrastructure and public transport. As mentioned above, they hardly represent congestion on roads and not crowding in public transport vehicles. Therefore, they neither represent delays caused by these phenomena. Now consider the possibilities for a public transport authority to model the consequences of increasing the frequency of bus services in peak. This will have as an immediate consequence, which is also captured by the models, that the waiting times at bus stops will be reduced, and hence demand will increase. If the demand increase is smaller than the capacity increase, there will also be less crowding on buses. The latter effect, will also increase demand, but if crowding is not modelled, the total effect is likely to underestimated. Furthermore, the effect on car use will also be underestimated. A secondary, or rebound effect, will be that the reduction of car use, and hence congestion in peak, will increase speeds and hence the attractivity of, and consequently the demand for using a car.

The need for analysis of the interaction between different policy instruments for urban transport have been discussed, e.g. in May et al. (2006). Such additional effects will not be discussed further in this paper.

A study of car use in cities worldwide (McIntosh et al 2014) estimates the elasticity of VKT with respect to increases in public transit supply to be -0,16. In these cities the elasticity of VKT with respect to urban density is estimated to be -0,20.

The wide variation in population density in Sweden and Norway can be expected to influence car ownership and car use. This is also what is found in recent studies of car use in Sweden (Pyddoke and Swärdh 2015 and Eliasson, Pyddoke and Swärdh 2016). The former study reports considerably lower elasticity of demand for vehicle kilometers traveled (VKT) in rural areas (in the magnitude of) -0,35 than in urban areas (in the magnitude of) -0,55. The dynamic structure of the estimation suggests that the long run elasticities are between 1.67 and 3.33 times higher than the short-run elasticities. In the latter study the distinction between different urban areas is further studied. As car ownership and car use is larger in smaller and peripheral cities than in larger and employment wise more central cities. Jussila-Hammes, Pyddoke and Swärdh (2016), controlling for several further variables, find a smaller elasticity of demand for car use with respect to fuel price in small cities in Sweden -0,15 than in larger cities -0,18.

The congestion charge has a direct effect on car transport demand both over the congestion charge cordon and elsewhere. Börjesson et al. (2014) discuss the transferability of congestion charge effects. The main conclusion is that although the benefits of a given charging system is considerably and non-linearly dependent on initial congestion levels, traffic effects and adaptation costs, the effects are surprisingly stable across transport system modifications. In particular, the degree of public transport provision has only small effects on baseline congestion, and therefore on the total benefit of the charges. Furthermore, contrary to expectation, the charges' effect on traffic volumes remains similar regardless of the changes in public transport.

The congestion charge has a direct effect on car transport demand both over the congestion charge cordon and elsewhere. The total effects where estimated to be reductions (-2,3 %) in inside the cordon whereas they were increases in the city as a whole (+2,8 %) and in the county (+0,9 %). (Trafikkontoret 2009). A rough estimate consequently is that CO_2 emissions developed proportionately. The effects over toll cordons were in the magnitude of 20-25 percent (Eliasson et al. 2009). In Trafikverket (2013) the Swedish Transport Administration examines the welfare effect of increasing the congestion taxes. The increases are shown to increase welfare. The agency (Trafikverket 2016) also reports that the increases in congestion charges in the magnitude from 10 to 75 percent gave a reduction on average of traffic of 6 percent.

For the demand for car trips with respect to the price of parking TRACE (1999) reports a total short term elasticity of -0,11. Hensher and King (2001) report considerably higher effects from parking prices on car use to the CBD. In the magnitude of -0,5 to -0,9 for trips to CBD.

Norheim (2006) reports that the supply of parking places in a city center is a strong factor behind car use and public transport market share, and reports a 0,09 elasticity of demand for car trips per inhabitant with respect to rate of supply of parking spaces to workplaces. Salon et al. (2012) refer to a number of studies. None of these are however directly comparable to the above.

Duranton and Turner (2011) use a large data dataset for the USA to test "the fundamental law of road congestion" or the hypothesis that road capacity in most cities is an important determinant for car use. The results suggest that this is so. In addition, Duranton and Turner (2011) also examine the hypothesis that public transport relieves the road system of car users. For this analysis the authors use the number of large buses operated in peak in large cities. They find that public transport supply does only have a small effect on car use. The conclusion drawn is that the estimates are consistently small and often not statistically distinguishable from zero. Anderson (2014), commenting on these results, emphasizes that in the most precise specification an average large bus could reduce VMT by up to 35 million miles. Beaudoin et al. (2015) report, the magnitude of this effect to vary substantially subject across urban areas: the elasticity of car use with respect to public transport supply varies from -0,014 for smaller, less densely populated regions with less-developed public transport, to -0,3 in the largest, most densely populated regions with extensive public transport networks.

Anderson (2014) main purpose is to examine the hypothesis that the car users in cities most likely to change to public transport are those experiencing the heaviest congestion on their commute route. Using data from a strike in Los Angeles the author concludes that although public transport in general is likely to have a small impact on car use in cities with significant congestion problems it is likely to have considerable positive welfare effects through its reduction of congestion. An important, implication of these results is therefore that public transport benefits in terms of reduced congestion externalities are likely to be substantial when congestion is extensive. If this occurs in large cities pricing of the congestion externality is also likely to produce welfare gains.

In a study of 26 large cities worldwide (McIntosh et al 2014) the elasticity of car use with respect to the supply of public transport is found to be around -0,16. Norheim (2006) finds a (-0,11) per inhabitant for European cities. In a forthcoming study (Jussila-Hammes, Pyddoke and Swärdh 2015) of Swedish cities a higher effect in larger cities -0,035 than the considerably smaller effect of public transport supply in smaller Swedish cities -0,018. For Stockholm Börjesson et al (2015) calculate the cross-price elasticity of demand for car use with respect to the price of public transport to be 0,48 and 0,11 in peak and off-peak respectively.

5 URBAN PUBLIC TRANSPORT

This leads over to the analysis of urban transport. One possible question is if improved public transport supply can contribute cost efficiently to decreases in CO_2-emissions? The above-mentioned calculations (Konjunkturinstitutet 2013) suggest that increased efficiency and fuel taxes can carry us most of the way needed to achieve the objectives. On the other hand the model does not cover how the demand for public transport will be affected by increased fuel prices. So while increases in the supply of public transport, taken in isolation, is likely to have impact on demand. The effect of increased supply taken simultaneously with higher fuel prices is likely to have a larger effect on public transport demand.

There are, however, a number of further reasons for wanting to reach for sustainable urban transport. These are improved accessibility, less congestion, less crowding in PT vehicles, less air pollution, noise and accidents and a fairer distribution of accessibility. All these effects may be conceived of as contributing to more "livable", "walkable" or attractive cities. In such cases the contribution of increased supply of public transport can be larger.

Most of the studies of public transport supply reviewed in this paper do not examine the interaction of national greenhouse gas policies with local urban land use policies. Some however do examine effects of fuel taxes although these policy instruments are in most countries a decided on a national level.

There are now a number of good surveys and meta-analyses of public transport demand and elasticities (e.g. Balcombe et.al. (2004), Litman (2014), Nijkamp and Pepping (1998), Holmgren (2007) and Henscher (2008)).

These all give suggestions as to what the behavioral response in terms of public transport demand might be to changes to on the one hand, individual variables like income, car ownership and residential area type, and one the other hand of strategic variables like fuel taxes, road pricing, parking supply, ticket price, headway and city form. An important limitation in these studies pointed out by Hensher (2008, p. 1038) is that most of these studies concern cities with relatively low market share for public transport.

In this study we will therefore seek out elasticities for cities with high market shares of public transport. A useful source for this purpose is Norheim (2006) which uses a database of European cities collected by UITP (the international association of public transport) extended with some Norwegian cities with a total of 86 observations of aggregate use of public transport and car. Of these, 31 cities are observed twice. The UITP set contains many capitals of Europe. For Swedish medium sized cities Nilsson Pyddoke and Ahlberg (2013) provide estimations of factors influencing demand.

An important caveat for many of these studies is that they do not estimate non-linear relationships. If a city's population grows this will in general increase the demand for public transport. An increase the supply in this context will in many cases increase the demand. In theory, increasing the supply beyond a certain level is however likely to give diminishing demand effects as the potential demand is exhausted.

5.1 The elasticity of demand for public transport with respect to price

For local and regional bus transport (bus transport in the sequel) in the UK Balcombe et al. (2004) note that the elasticity of demand with respect to price on average is estimated to -0,4 in the short run and to -1,0 in the long run. For passenger train services the elasticity of demand with respect to price is found to be -0,6 in the short run (Balcombe et al. 2014). It may be noted that a predecessor to Balcombe et al. (2004) namely Webster and Bly (1980) recommended -0,3 as a rule of thumb for the elasticity of demand with respect to price. Later surveys have gravitated towards -0,4 (eg. Balcombe et al. 2004 and Holmgren 2007).

Tabell X Fare elasticities for public transport

Elasticity of demand with respect to fares		Spread		
	Average	from	to	Meta
Public transport UK generally	-0,44	-0,07	-1,02	Saknas
Bus UK short run	-0,42	-0,07	-0,86	-0,36
Bus UK long run	-1,01	-0,85	-1,32	-0,70
Bus UK peak short run	-0,26	0,00	-0,42	-0,30
Bus UK off-peak short run	-0,48	-0,14	-1,00	-0,40
Commuter trains UK short run	-0,58	-0,10	-1,02	-0,50
Commuter trains UK peak	-0,34	-0,27	-0,50	Missing
Commuter trains UK off-peak	-0,79	-0,58	-1,50	Commuter trains

Källa: Balcombe et.al. 2004 Table 6.55

Tabell X Model estimated elasticities for short and long run

Elasticity with respect to	Europe short run	Europe song rund
Public transport fare Conf. interval 95%	-0,75 (-0,55 till -0,95)	-0,91
Supply kilometers	1,05	1,38
Income	-0,62	-0,62
Petrol price	0,4	0,73
Car ownership	-1,48	-1,48

Source Holmgren 2007 Table 7

Holmgren does not give any definition or formula for the calculation of short and long run elasticities. Long run elasticities are usually calculated using estimations of a lagged effect. It may be noted that Holmgren finds a higher elasticity with respect to price but it should then be kept in mind that the model structures are not directly comparable.

Norheim (2006) finds an elasticity of demand for trips per inhabitant with respect to price of -0,32 for European cities in the extended UITP dataset. In Nilsson et al. (2013) an estimate of the elasticity of demand with respect to prices for 17 medium sized Swedish cities is found to be -0,39.

Studies of public transport in Norway (Ruud et al. 2010, Norheim 2012, Ellis and Øvrum 2014) discovered large differences in average values of time between individuals with different income Norwegian cities, with larger cities having larger average values of time. These differences in valuation of travel time are positively correlated to income. This is shown in for Sweden (Börjesson et al 2012). In cities with larger shares of high income earners using public transport this appears as higher average time values for public transport users. Such differences in time value are likely to affect the individual's sensitivity of demand to price, frequency and speed.

There are some empirical studies analyzing the welfare effects from changing lower prices or increased supply of public transport. Examples (de Borger et al. (1996), Parry and Small (1999), Proost and van Dender (2008)) present estimates that indicate that optimal prices to be substantially below marginal operating costs.

5.2 The elasticity of demand for public transport with respect to supply

There are some studies that estimate the effect of increased supply of public transport on the number of trips. The supply can be measured as vehicle kilometers, frequency of departures and travel time. For a given set of routes, the first two measures can be expected to be closely correlated as an increased frequency must be associated with more vehicle kilometers. A higher frequency may also be associated with shorter waiting times and hence less total travel time. But more supply kilometers may also be generated by new or extended routes without increases in frequency.

On similar grounds that the sensitivity of demand with respect to price may vary between modes of transport, geographical areas and time periods, the sensitivity with respect to supply may also vary and therefore variations in supply may have very different effects on the number of trips. The empirical studies on such a detailed level are however few.

For the demand for bus transport with respect to supplied vehicle kilometers Balcombe et al. (2004) present the following estimates of elasticities 0,4 in the short and 0,7 in the long run (p 73). Preston och James (2000) find elasticities with respect to waiting time (a proxy for frequency or bus kilometers) in 23 British cities to be -0,64. Norheim (2006) finds an elasticity of demand for public transport trips per inhabitant with respect to supply of vehicle kilometers per inhabitant of 0,6 for European cities. Nilsson et al. (2013) present an estimate for short run elasticity of demand with respect to supply of vehicle kilometers for 17 medium sized Swedish cities of 0,7. This estimate does not control for the length of the route net.

5.3 The elasticity of demand with respect to population size and population density.

Norheim (2006) finds that the elasticity of the demand for public transport trips per capita with respect to population size is -0,21[4] and to population density 0,36 for European cities. Nilsson et al. (2013) find that the total demand for public transport with respect to population size has an elasticity of 0,48 and population density 0,17 for bus transport in medium sized Swedish cities.

It is not obvious that population size or population density in themselves should influence demand per capita. Two possible mechanisms may generate such a pattern. Growing cities are likely to experience increasing congestion in central areas and parking is likely to become scarcer and costlier. Both these effects may in turn induce car users with high time valuations to shift to public transport in larger cities.

5.4 The elasticity of demand with respect to speed

[4] This result suggests that population size is not associated with more public transport use.

Congestion in streets and increased costs for finding and using parking spaces creates an opportunity to attract car users with high time valuations to public transport by improving the speed of public transport. This has led to attempts to explore these higher valuations. The most obvious is by restructuring bus routes and increasing speeds by creating exclusive bus lanes, introducing signal priority at intersections, reducing bus stops and increasing frequency. In several consultancy studies (e.g. Kjørstad et al. 2015) Urbanet Analyse has simulated the possibility to increase bus patronage with up to 30 percent by concentrating capacity to a smaller number of trunk lines with higher speeds. This is possible without introducing more capacity or increasing public funding.

5.5 The elasticity of demand for public transport with respect to income

Direct effects of increased income may be both increases in demand for public transport and increased car ownership. An indirect effect of increased car ownership may in turn be less public transport demand.

The direct effect of increased income on public transport demand

The following estimates with a structural model of national time series data for bus and car use were presented by Dargay and Hanly (1999).

The direct elasticity of demand for public transport with respect to income and car ownership

	Bus passenger kilometers	Bus trips
Income; Short run	0,14	0,38
Income; Long run	0,07	-0,26
Car ownership; Short run	0	0
Car ownership; Long run	-0,73	-0,64

Source: Balcombe et.al. (2004) p 117

The above estimates are not differentiated with respect to area type for which the estimate is performed. The following estimates presented by Balcombe et.al. (2004) also using aggregate data differentiate with respect to area types (Clark, 1997). Norheim (2006) finds an elasticity of demand per inhabitant with respect to income of 0,13 for European cities.

Bus demand elasticities differentiating with respect to area types.

	London	Metropolitan	Non metropolitan
GDP	0,19	0,41	0,43
Car ownership	-0,70	-1,04	-1,23

Source: Balcombe et.al. (2004) p 117

These results indicate that bus use is less affected by general income level and car ownership in London than in other metropolitan areas and even less so than in non-metropolitan areas. These figures also indicate that income increases are likely to affect public transport in cities less than in rural areas.

5.6 The elasticity of demand for public transport with respect to of fuel prices, congestion, congestion charging and parking supply and price

Fuel price

Increased fuel prices reduces demand for car travel and car ownership. This can also lead to increases in the demand for public transport. Balcombe et.al. (2004) report high cross elasticities between fuel price and demand for public transport. The short run cross elasticities being 0,72 for rail demand in urban areas and 0,35 for bus demand.

Short-run public transport cross elasticities with respect to fuel price

Urban bus	0,35
Urban rail	0,72

Source: Balcombe et.al. (2004) p 106

Long-run public transport cross elasticities with respect to fuel price

Urban bus	2,1
Urban rail	1,0

Source: Balcombe et.al. (2004) p 106

de Jong and Gunn (2001) report a considerably lower total cross-elasticity from fuel price to public transport demand 0,18 from the Netherlands national travel demand model.

The corresponding long run elasticities from the regional models in the Swedish national travel demand model (SAMPERS) are also considerably lower 0,1 and 0,06 for bus demand in the southern most county in Sweden, Scania, and two other rural regions respectively. The corresponding figures for rail demand are 0,18 and 0,12 respectively. Velasco (2010) reports a short run elasticity for demand for monthly cards for public transport in Stockholm county with respect to fuel price of 0,2.

Johansen (2001) presents elasticities of public transport demand with respect to fuel prices calculated by Norheim and Renolen (1997) in the range from 0,2 to 0,3 which is quite close to the Velasco (2010) study. Minken (2005) points to Carlqvist and Fearnley (2001) who estimate the elasticity to be on average 0,14 in seven Norwegian cities. Norheim (2006) finds an elasticity of demand per inhabitant with respect to gasoline price of 0,26 for European cities.

5.7 The contribution of improved public transport to reduction of greenhouse gas emissions

In a forthcoming paper on the effect of public transport supply on car use (Pyddoke et al. 2016) find the elasticity of demand for car use with respect to public transport supply in Sweden is a higher effect in larger cities -0,035 and considerably smaller in smaller cities -0,018.

Nilsson, Pyddoke and Andersson (2013) present two estimations of the effects of policies for increasing public transport demand. In the first estimation it is assumed that a doubling of public transport travel has been attained. This calculation answers the question of what if, but of not how. The growth in demand is assumed to be distributed in the same proportions as the forecasted growth in the national demand forecast. Half of the new person kilometers in public transport are assumed to derive from a reduction of person kilometers of car travel. In this example the sum of the effects of increases in public transport and reduction amounts to a reduction of carbon dioxide emissions of 6 percent compared to the forecast scenario.

In the second estimation the effects of a combination of i) a reduction of public transport fares with 25 percent ii) an increase of gasoline taxes so that the price increases by 25 percent, and iii) an elimination of the right to deduct work travel expenses from taxable income. The effects of these drastic measures are calculated to be a) an increase in passenger transport in local bus by 37 percent and commuter trains by 64 percent.

Congestion

It would be very useful to know more about how congestion directly affects public transport demand. This would require good simultaneous data on the level of congestion and the level of public transport demand. No study using such data has been found.

Congestion charges

Congestion charges stimulate public transport use. Börjesson et al. (2014), studying Stockholm, estimate that 30 percent of the car drivers ceasing to drive on account of the congestion charges diverted to public transport. The number of passengers by public transit was 6 % larger in spring 2006 than 12 months earlier (Cited from Eliasson et al. (2009) Stockholm Transport (2006a)).

The congestion charges in Stockholm were, however, not found to have a statistically significant effect on demand for monthly cards for public transport in Stockholm County in Velasco (2010). Minken (2005) discusses the subject and suggests that there may be considerable synergies between congestion charges and public transport but does not conclude with an estimate for Norway. The effects on public transport demand of the Stockholm congestion charging scheme have been presented in one of several papers (Eliasson et.al. 2009, Börjesson et.al. 2014) but with important caveats. The effects were calculated to be in the range of 5-6 percent of the number of car drivers.

If a car trip to Stockholm center is 50 kilometers and fuel cost per kilometer is 14 SEK/liter, fuel efficiency 0,06 liters/km, the congestion charge is 20 SEK, then the congestion charge corresponds to a fuel cost increase of around 50 percent. With a cross elasticity of 0,2 this would divert 10 percent of the car drivers to public transport.

5.8 The elasticity of public transport demand with respect to parking supply and costs

Litman (2014) gives a useful survey of elasticities related to parking. For the demand of public transport trips with respect to the price of parking TRACE (1999) reports a total short term elasticity of +0,03. Hensher and King (2001) report considerably higher effects from parking prices on public transport use to the CBD. In the magnitude of 0,29 for public transport trips to CBD.
For the supply of parking spaces in European cities Norheim (2006) finds an elasticity of demand for public transport per inhabitant of -0,23 with respect to the rate of supply of parking spaces to workplaces.

5.9 Welfare consequences of urban parking prices

In several studies van Ommeren together with various co-authors (e.g. 2011, 2012 and 2014) has pioneered empirical analysis of welfare consequences of parking policies. In van Ommeren, Wentik and Dekkers (2011) data from Amsterdam are used to estimate the private costs for residents cruising for parking spaces and the willingness to pay for on-street parking permits. The calculations demonstrate that the willingness to pay for on-street parking permits by far exceeds the parking permits tariff, which in turn is far below the on-street tariff for non-residents. This suggests considerable efficiency losses in the allocation of parking capacity. The most immediate consequence being that residents parking crowds out non-residents with higher willingness to pay at least for parts of use in a day.
In van Ommeren and Russo (2014) the analysis of the welfare consequences of parking policy is extended to variation in demand over a day and over a week. In this case, data from a Dutch hospital which has applied a charge differentiated over the week to its parking are are used. This hospital lies in an area where street parking is charged. It is assumed that the parking is provided by the hospital with the objective of maximizing profits from the provision of parking. The analysis starts with the observation that there are variations in demand for parking between days. The most important conclusions are that offering parking for free will induce dead weight losses in the magnitude of 10 percent of the annual resource costs for providing parking. Charging a minimum loss uniform tariff every day will induce losses.
These studies suggest that common practices may imply to low parking prices and that too little differentiation. The conclusion however depends on the assumptions of alternative costs for land and the specific local demand patterns.

6 THE DENSITY OF CITIES AND THE POTENTIAL TO INDUCE LESS CAR TRAVEL

The observation that density of cities is correlated with lower energy consumption and hence less CO_2-emissions (Brownstone and Golob (2009), Glaser and Kahn (2010)) has led to the notion that compaction of cities could lead to less transport and a more sustainable development (see Echenique et al. (2012) for references to reviews). This in turn has led to a number of studies looking closer at the relationship between density and CO_2-emissions. This section summarizes some recent contributions to this literature.

Cervero and Murakami (2010) study the effect of different dimensions of built environment (the four D's: density, diversity, design and destination accessibility (connectivity)) on vehicle miles traveled (VMT) as a proxy for the potential of reducing greenhouse gas emissions. The basis is a data set from 370 urbanized areas in the USA. The results show that population density has a total effect (direct minus indirect effect) in elasticity terms of -0,38. The direct effect is -0,6. The measures of accessibility only show modest effects, as do area size and the presence of rail-transit. High population densities and high accessibility to retail, service and trade induce car travel. A likely mechanism behind this observation is the presence of large shopping malls increasing the density of shopping opportunities and inducing longer car trips. In the north-east region the sign is reversed, possibly due to that traditional retail districts in northeastern cities are more walkable and hence attractive.

The role of urban form and public transport for car use are studied in MacIntosh et al. (2014) using a data set including 26 cities over 40 years. They characterize four city types: *Full Motorization, Weak Centre Strategy, Strong Centre Strategy and Traffic Limiting Strategy*. These categories represent an increasing degree of city structure facilitating the use of public transport and are characterized by the following features. The *full Motorisation Strategy* cities has small or no city centre, employment in low buildings, low density single storey suburbs. *Weak Centre Strategy* cities have a small city centre (more than 250 000 jobs). Significant suburban employment served by car. Ring and radial freeways. The *Strong Centre Strategy* cities have, a strong CBD with more than 500.000 jobs, a radial transit network, and limited road accessibility to the centre, ring roads and transit provide access to centre, development outside centre focused on transit infrastructure. *Traffic Limiting Strategy* city centre hierarchy structured to minimize need for travel, radial rail and ring rail systems, all centres accessible by transit, bus, cycling or walking as well as car, limited access to centre with car and high cost of car travel (parking, congestion charging).

Among cities categorized as Full Motorization were Houston, Denver and Los Angeles. Weak Centre Strategies were Washington, Chicago, Brisbane, Montreal, Calgary and Copenhagen. Strong Centre Strategy were New York, Toronto, Sydney, Frankfurt and Hamburg. Traffic Limiting London, Brussels, Vienna, Zürich and Stockholm

Using this categorization and a number of variables four structural equations were estimated:

- Car VKT per capita as a function of public transit passenger kilometers, urban density and region and time dummies
- Public transit passenger kilometers as a function of transit kilometers transit service, urban density and road length per capita
- Urban density as a function of transit kilometres of service
- Road length as a function of urban density and transit kilometers of service

The most important results are the following. The average growth of VKT per capita in the 26 cities is 120 percent since 1960. There are large average differences in VKT per capita between the regions USA, Canada, Australia and Europe. The *traffic limiting* archetype had the lowest car use and the highest density. The *strong* and *weak center* cities had about the same car use but marked difference in density (with strong center having higher density). The *Strong center* cities have the highest transit use followed by the traffic limiting cities, the weak center and the Full motorization strategy cities.
In the studied models both give estimates of the elasticity of VKT with respect to increasing urban density and increases in public transit supply, with -0,20 and -0,16 respectively. The authors conclude that the study "indicates that urban density and transit service provision have causal relationships with private vehicle travel and are additional to the influence of the region" and structure of cities (McIntosh et al 2014, p 109).
Larson et al. (2012) study the impact of urban land use and transportation policies present results from simulations with numerical urban simulation models. The calculations use both empirical relationships from the US Energy Information Administration's Residential Energy Consumption Survey and a spatial model for cities. Furthermore, the model is calibrated on five reference cities in the USA. This model allows for analysis of the effects of changes in policy like land use zoning and increases in gasoline taxation on housing markets and residential location and ultimately on energy consumption for residential and commuting purposes. The model does not represent public transport.
With a gasoline price increase by $2 per gallon the city then becomes more compact, with the area shrinking 10,3 %. The density of housing at the edge of the CBD increases by 11,3 %. The share of one family detached units falls by 6,7 % and the share of multifamily units increases by 6,3 %. The relative reduction in utility of low income households is three times larger than the utility loss of high income households (p152).
An increase in vehicle fuel efficiency by 25 % leads to increase of the area of the city by 2,1 % and commuting times by 1,3%. Housing density and prices decrease near the center. Lower transport costs leads to lower density and hence increase in the total space occupied by the city and consequently longer commuting distances. Total energy consumption falls by 1,8%. The utility of low income households rises relatively to high income households (p 153).
Rising household income by 10% expands the city's area by 11,8%, but also increases density at all locations. Commuting time increases by 4,8 % energy consumption in housing by 3,6% and commuting by 6,9%.
Increasing land for open space raises residential land prices, increasing density and inducing a substitution towards multi-household housing and decreasing the

average space of a housing unit. The net effect being a 2,5 % increase in total city area. Furthermore a 1,1% increase in energy consumption for commuting. Totally almost energy neutral. Ignoring the utility of the open space the utility of low income households falls more than higher income households.
Imposing a greenbelt 9 miles (14,5 km) from the city center leads to a decrease of energy use for commuting by 6,1 % and for housing by 0,9%. As housing use of energy (in the US) is seven times that of commuting the energy saving is approximately the same.
Zoning and floor area ratios limiting the degree of development of a city center may affect density. Assuming a limit of floor area ratio of 1,4 instead of the 2,2 at the CBD boundary in the base line scenario raises house prices, particularly for low income households. And the area covered by multifamily units increases with 13%. The density decreases though, decreasing the total number of multifamily units.
The authors conclude that substantial differences in energy use and CO_2-emissions suggest that characteristics of the urban development process may have a strong influence on energy use in cities. The authors also point to the importance of modeling effects including indirect and feed-back effects. A dramatic example is the effect of increased fuel prices leading to reductions in household energy use due to choice of smaller and more densely built units.

7 DOUBTS ARISING CONCERNING THE EFFECTS ON CO_2-EMISSIONS AND WELFARE FROM INCREASING DENSITY

Some recent studies on the relationship between land use policies and energy consumption or CO_2-emissions are skeptical about the potential of such instruments. van Wee and Handy (2014) compare a small number of longitudinal studies, in which a *change* in travel behavior following a *change* in land use are assessed, to a larger number of cross sectional studies. The longitudinal studies show much smaller effects than the cross-sectional studies. Land use patterns may have an impact travel behavior, but the most important effects may be improved accessibility. van Wee and Handy (2014) also argue that land-use policies should be evaluated by a broader set of benefits. They claim that land use policies should not be expected to yield important contributions to CO_2-emission reductions but may have important accessibility benefits.

One important argument in the literature (van Wee and Handy (2014)) is that some of the differences observed in cross sectional studies may be due to selection effects where people with preferences for traveling less by car or more by public transport chose housing locations in denser areas or areas with good public transport. Ellis and Parolin (2010) e.g., examine travel behavior at previous residence and current residence of inhabitants residing in areas near train stations on the Sydney rail network. Results showed that subjects had higher than average public transport use in Sydney. However, this was also the case before these subjects moved close to the station. This creates an apparent, not actual, influence of urban form on travel behavior.

Most of the studies we have found have studied the USA. Echenique et al. (2012) studying the UK being an exception. Few of these explicitly study the prevalence of public transport and its impact on vehicle miles traveled. Echenique et al. (2012) use detailed data and calibrated models for three city regions in the UK to model a reference scenario and three different planning strategies in a 30-year perspective. They find only small effects 3 percent compared to reference scenario and 5 percent (maximum) reduction of CO_2-emissions. Hence they conclude that policies directly targeting CO_2-emissions are more likely to be more effective.

8 DISCUSSION

As the population of the largest cities in Norway and Sweden are growing fast, politicians are challenged to find solutions for how to plan cities and provide transport. At the same time the ambitions to curb greenhouse gas emissions are also increasing. Faced with these challenges citizens and politicians have gravitated to thinking that making public transport so attractive that car drivers voluntarily will choose to use public transport, as well as planning new housing along public transport corridors is a solution. Public transport can be made more attractive by increasing frequency, density of the network or by decreasing fares. The purpose of this paper is to survey policy models used to develop more sustainable transport systems for urban areas and compile estimates of their effects. In the present context "policy model" is interpreted widely as all models that can guide the use of a policy instrument. For this purpose, the paper reviews literature on the effects of policy instruments that may induce less greenhouse gas emitting transport and congestion. We cover the following types of policy instruments; fuel taxes, congestion charges, parking fees, variation in the pricing and supply of public transport and an increased density of urban areas.

The effects of increased populations and incomes are likely to be an increased demand for transport and higher average valuation of time. Some of this is likely to materialize as demand for car use. The increased car use creates road congestion and other externalities. Current transport demand models for planning are, however, not built to represent congestion accurately. Therefore, current and future congestion problems are presently likely to be underestimated by todays models. Increased road congestion will slow down both cars and buses.

The prevalence of congestion can justify policy even in the absence of carbon emissions. The fleeting nature of the congestion problem requires planners to be well informed on the regularities of its existence. The knowledge of effects of congestion charges in larger cities is now accumulating and the instrument shows good effectiveness and efficiency. For smaller cities the magnitude of the problems may not motivate the system costs of a congestion charging system. The knowledge of alternative policy instruments to curb congestion, like availability of parking and parking fees, are still patchy. More congestion in streets and roads may call for priority for buses. This can be achieved with bus lanes and signal priority. Buses can also be made more attractive.

Slower car transport is likely to shift demand from car to public transport, walking and cycling. This in turn is likely to increase crowding in public transport. As current models do not represent crowding in public transport, the demand effects of increased supply of public transport can be underestimated. This is so if the increases in supply lead to less crowding and shorter travel times.

Similar to public transport, where an increase in the demand may increase the potential for increasing supply, increasing demand for cycling may also create a potential for improving cycle infrastructure. Crowded cycle infrastructure is also likely to reduce demand.

Cross section studies indicate that effects from denser habitation may reduce the demand for car travel and increase the demand for walking, cycling and public transport. The other way around, increased transport costs will tend to reduce the space occupied by a city. Longitudinal studies, however, suggest that the effects are smaller although the precise mechanisms and the magnitude of the effects are not known. Also, most regulations of housing supply reduce welfare. The conclusion is therefore to be wary against far reaching land use policies as the full consequences of such policies are not well known.

9 CONCLUSIONS

National multisector models have been used to simulate general policies for CO_2-emission reductions. These suggest that the theoretically most efficient taxes on CO_2-emissions may carry Scandinavian countries most of the way to official targets.

Car use in Sweden is shown to be more price sensitive in urban than in rural areas, and larger the larger the city. Policy instruments targeting car use in Scandinavia have shown that these are effective and in some cases welfare improving. Congestion charges have been shown to significantly reduce car use and congestion and to improve welfare. Although the benefits of a given congestion charging system are considerably and non-linearly dependent on initial congestion levels, traffic effects and adaptation costs are surprisingly stable across transport system modifications. The demand for car travel is largely insensitive to supply of public transport and on baseline congestion, and therefore on the total benefit of the charges. Parking fees are also shown to be effective in reducing car use. The effects of parking fee levels on congestion and welfare are, however, less well known. Studies of the effects of public transport supply on car use indicate that these effects generally are small but can be large in larger cities and in cities with heavy congestion. This suggests that policy instruments targeting car use and congestion are likely to have beneficial effects if there is congestion.

Improving public transport can be justified if it improves accessibility and social welfare. It may also be an important complementary instrument to policy instruments that reduce car use. This paper has collected estimations the elasticity of demand for public transport from international surveys and Scandinavia, with respect to public transport prices, public transport supply, speed, income, population size and density, fuel price, congestion charges, parking supply and prices. Both population size and population density appear to independently influence public transport use. The welfare effects of public transport supply and its subsidization are less well known.

Finally, the paper discusses the potential to reduce car use, CO_2-emissions and congestion by land use planning in cities. Cross section studies, some longitudinal studies and simulation studies suggest that cities with denser populations and conscious strategies to reduce car use and provide public transport show considerably less car and energy use. Some recent studies have, however, raised doubts about the effectiveness and efficiency of using land use planning to influence car use and CO_2-emissions. Although the effects of land use policies can be beneficial, their effects are generally less well known than policies addressing transport congestion externalities. As these are better known and likely to be welfare improving the effects of policy instruments associated with congestion pricing, parking pricing, improvements of the supply of public transport are likely to be preferable.

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