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An ex-post CBA for the Stockholm Metro

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Abstract

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Keywords: *Ex-post evaluation; Cost-benefit analysis; CBA; Appraisal; Land-Use modeling; Metro; wider economic impacts; rail investments*

JEL Codes: D61, R41, R42, C25, J22

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This paper performs an ex-post cost-benefit analysis (CBA) of the Metro system in Stockholm built in the 1950s. We find that the Metro was socially beneficial and that the largest benefit of the Metro is its capacity, making it possible for many people to travel to and from the city center. We also assess the significance of the wider economic impacts due to labor market distortions and the land-use effects in the case of the Stockholm Metro. The wider economic impacts increase the consumer surplus with 48%, and the yearly income in the county with 3.7%. A land-use model is used to analyze how the land-use has been influenced by the Metro over the years 1956-2006. The land-use model indicates that the historical centralized planning of housing along transit corridors has developed the region into a more dispersed region than if it had been planned according to the present inhabitants' preferences. Moreover, we find that the land-use impacts from the investment itself seem to be small, but the land-use impacts from planning accompanying the decision to build the metro have been substantial.

1 Introduction

Anyone who works with cost-benefit analysis of transport investments will recognize statements such as: “Cost-benefit analysis cannot be used to evaluate large transformative (rail) investments. Simplifying assumptions and omitted effects imply that such investments never pass a cost-benefit analysis.”[1] Examples vary between countries, but in Sweden there is the anecdote that “the wonderful Stockholm Metro would not have passed a CBA when it was built in the 1950s.”[2] However, the full costs and benefits of the Stockholm Metro were not assessed at the time nor have they been since.

The anecdote aims at discrediting standard cost-benefit analysis (CBA), but it is still true that applied CBA is relying on simplifying assumptions and omits effects that are difficult to measure. In many cases such simplifications and omissions will be irrelevant, but in some cases – typically large projects in urban regions – they might have a significant impact (De Palma, 2011; Worsley, 2011).

The first objective of this paper is to perform an ex-post cost-benefit analysis of the metro system in Stockholm. Such ex-post analyses are rare but rewarding, displaying both the benefits of the Stockholm Metro and methodological issues relating to both transport modeling and scenario assumptions. Two of the most important omitted effects in CBA are the wider economic impacts due to labor market distortions and the land-use effects. A second objective of this paper is to assess the significance of these effects in the case of the Stockholm Metro. The difficulties and method of assessing these are not specific to Metro systems but apply to most large urban transport investments.

We use standard Swedish CBA guidelines and models to perform a CBA for the 1950s and we analyses how the land-use has been influenced by the Metro over the years 1956-2006, using a LUTI model. A hypothetical land-use is simulated under the assumption that the Metro system was not built in the 1950s.

Like all cost-benefit analyses this analysis inevitably ventures into counterfactual propositions, which tend to make historians uneasy, because it requires hypothetical alternative scenario assumptions. However, in an ex-post analysis such as this, counterfactual assumptions induce less uncertainty than in standard ex-ante analyses. First, at least one of the infrastructure scenarios exists and does not need to be constructed. Second, many exogenous factors, such as economic growth, population growth and different societal trends, including preferences of individuals and firms, are uncertain in an ex-ante analysis but are known in an ex-post analysis. Third, an ex-post analysis will not be used as a decision support, so it does not run the risk of being biased due to a strong political pressure.

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[1] Peter Eriksson och Karin Svensson Smith (both Green Party), svenska dagbladet, Brännpunkt 21 maj 2010.

[2] Stig Dingertz (M), intervju publicerad på www.stockholm.se/-/Nyheter/Om-Stockholm/Hans-sparvagside-blev-succe/
Maria Nygren (TransportGruppen), www.transportfakta.se/Debatt/?date=2009-10-01.

Wider economic impacts due to labor market distortions, such as income taxation and agglomeration effects, have been subject to considerable attention and debate from researchers and policy-makers (Graham & van Dender, 2011; Lakshmanan, 2008; Venables, 2007). Such benefits are not regularly considered in Swedish transport CBA because the quantification of them is regarded to be too uncertain. An estimate of these benefits is, however, often added as a sensitivity analysis, using an estimated relationship between wages and workplace accessibility computed by the transport model (Anderstig et al., 2012). In this paper we use this relationship to assess the wider economic impacts of the Metro. It is similar to the relationships estimated between productivity and effective density reported in the literature (Rice et al., 2006; Ciccone & Hall, 1996; Combes et al., 2010), but the accessibility measure is more consistent with the CBA framework since it is computed directly in the transport model.

Long-term location responses to accessibility changes may help investments to create their own demand. Such responses are well established (Litman, 2007; SACTRA, 1999; Goodwin & Noland, 2003; Hills, 1996; Noland, 2001) but are seldom taken into account in appraisal. Advocates of Smart Growth argue that transit investments can help achieve higher density, while new highway investments tend to lead to the opposite, i.e. more urban sprawl (Bernick & Cervero, 1997; Newman & Kenworthy, 1989). If this is the case, induced land-used effects will also affect the CBA outcome due to increased positive or negative externalities such as congestion and pollution as well as increased optimal service frequency of transit (Mohring, 1972). Geurs et al. (2010) show how benefits from land-use changes can add a substantial benefit to a CBA, employing a Land-Use and Transport Interaction (LUTI) model.

Taking land-use effects into account in project appraisal may be important in cases where the investment and land-use policy are integrated, as they were in the case of the Stockholm Metro. The Metro was accompanied by a planning strategy to locate housing along transit corridors (Cervero, 1995). At the beginning of the 1950s, the inhabitants of Stockholm suffered from low housing standards and severe crowding due to a rapid increase in population. The centralized housing planning was also made possible because the Stockholm City Council had pursued a policy of acquiring land since 1904, and in 1980 owned 70% of land within its borders (Cervero, 1995). The basic planning strategy of developing residential areas along transit corridors has prevailed in the region since the 1950s.

Ex-post cost-benefit analyses of large urban investments such as the Stockholm Metro are rare. However, one of the first systematic theory- and statistics-based studies in economic history using a counterfactual scenario was Fogel (1964). He attempted to quantify the effect on American economic growth of the railroads built up until 1890, finding that removing all railroads in 1890 would have decreased the GNP of year 1890 by 4.7% (Fogel, 1964, p. 234). The main conclusion was thus that "no single innovation was vital for the economic growth during the nineteenth century". While this study launched heated discussions over methods and in particular the use of a counterfactual scenario (Fremdling, 1977; McClelland, 1968; Redlich, 1965), few question its merit as a systematic and quantitative study. In more recent years the bulk of ex-post analyses are primarily comparing forecasts of transport demand and construction costs with outcomes, occasionally updating earlier cost benefit analyses (e.g. Flyvbjerg et al. 2003, 2005). A similar approach to ours can be found in Geurs and van Wee (2006) who study the impact of compact town planning in the Netherlands, although not with the focus on CBA.

Section 2 describes the Stockholm Metro and Section 3 describes the method of analysis, including scenario development, CBA parameters, the method of assessing wider economic impacts and effects on land-use. Section 4 describes the transport and LUTI models. Section 5 presents results, including traffic effects, the CBA, the wider economic impacts and land-use impacts. Section 5 discusses the results and Section 6 concludes.

2 The Metro

The first part of the Stockholm Metro was opened in 1950 and most of the system was completed by 1960, although further parts were added until the middle of the 1970s. The present track length is 105 kilometers, of which 62 kilometers are in tunnels, with a total of 100 stations spread over three lines, see Figure 1. The decision to build the Metro was taken by the Stockholm City Council in 1941. At the time, the City of Stockholm was the major land-owner in the municipality and responsible for both housing planning and transit infrastructure provision and operation. At that time the transit system consisted of buses, commuter trains and trams. The latter covered most of the central parts of the present Metro system.

At present the Metro is central for commuting to the city center (where most of the workplaces are located). The share of transit trips to and from the inner city reaches 75% during peak hours, and the Metro takes 57% of all transit trips to and from the city center[3]. There are also commuter trains, trams and buses running to and from the inner city.

The high share of transit trips is due to the well-developed transit system, but another factor is that the inner city of Stockholm is built on several islands, connected by bridges, which imply relatively high road congestion for a city of comparable size (2 million in the county of Stockholm). The bridges connecting the inner city to the outer city are bottlenecks in the road network.

The total cost of the Metro system was €0.5 billion4 in 1975 prices (Asker & Falk, 1975)[5]. Multiplying this cost with the price index for the construction sector 1975-2009 (SCB, 2013), the cost is found to be €5 billion in 2009 prices.

[3] 57% of these transit trips use Metro, 16% buses, trams 5% and 22% commuting trains.
[4] Here and through the rest of this paper we used the conversion rate 1 SEK = 0.1€.
[5] Corresponding to 0.5 Billion € in 1975 prices.

For this period, the price index for construction sector is twice the average price index for all sectors. Moreover, an expert assessment of the hypothetical construction cost of building the Metro in 2009 (had it not been built in the 1950s) is €11 billion (€0.1 billion per km)[6]. Hence, the prices of infrastructure construction have increased considerably faster than the prices in other sectors, and also faster than in other construction sectors[7]. The operation of the Metro cost €0.28 billion in year 2009.

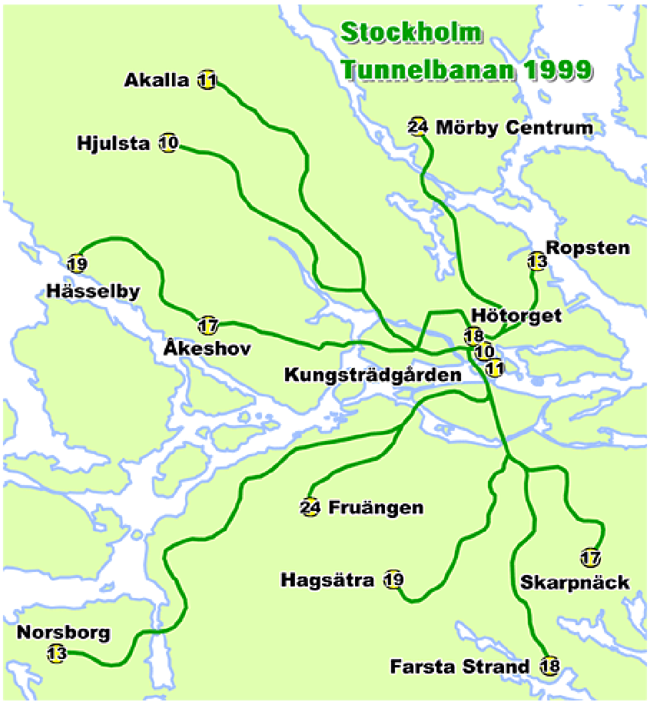


Figure 1: The Stockholm Metro. Hötorget-Hässelby is 15 km and Hötorget-Farsta Strand is 13 km. The inner city is marked by the dotted lines.

3 Method

This section describes the method of the ex-post cost-benefit analysis (CBA) of the Metro, including scenario development and basic CBA parameters. Section 3.1 describes the scenario without the Metro and section 3.2 reports the general CBA parameters. Section 3.3 describes how alternative land-use scenarios are generated and section 3.4 describes the method of computing wider economic benefits.

We present two cost-benefit analyses in this paper. Both investigate the Metro investment, but apply different assumptions concerning the land-use patterns. The first CBA is a standard analysis of the Metro, assuming that the present,

[6] Oral communication with SL, Stockholm Public Transport.

[7] One factor for the low cost is that construction of central parts of the Metro coincided with a major reconstruction and modernization of the Stockholm city. Tunnels were built from the ground, which is considerably cheaper than to cut the tunnels, and many buildings were torn down. A second factor is that there are now more rigid regulations concerning safety standards and air quality than in the 1950s. There may be more factors behind the relatively slow increase in productivity in these sectors, which are beyond the scope of this paper.

historically developed land-use is exogenous and thus not affected by the Metro. Since the building of the Metro was so well integrated with the planning of the land-use of Stockholm, and because of the population growth in Stockholm since 1950, it is beyond doubt that the Metro has had far-reaching effects on the urban form. In the second CBA, we therefore assume a second land-use scenario, simulated by applying a separate LUTI model, under the assumption that the Metro system was not constructed. The four combinations of two land-use (historical-simulated) and the two infrastructure (metro-tram) scenarios making up the two cost-benefit analyses are described in Table 1.

Table 1: All costs are given in 2009 prices

CBA	***'CBA with given land-use'***		***'CBA with simulated land-use'***	
Scenarios	***'Metro/Historical'***	***'Tram/Historical'***	***'Metro/Simulated'***	***'Tram/Simulated'***
Infrastructure	Metro	Tram	Metro	Tram
Land-use	Historical	Historical	'Simulated with tram'	'Simulated with tram'
Population growth	1.4% per year			
Travel time	Current Metro travel times	Twice the Metro time	Current Metro travel times	Twice the Metro time
Service frequency	Current Metro frequency	Twice the Metro time	Present Metro frequency	Twice the Metro time
Capacity	Present Metro capacity	Twice the Metro time	Present Metro capacity	Twice the Metro time
Road infrastructure	Historical			
Forecast year	2006			
Appraisal year	1956			
Appraisal period	1956-2006. Benefits are assumed to increase linearly with traffic growth.			
Value of time	Assessed weighted average for the appraisal period. These also correspond to the 2009 national guidelines.			
Valuations and CBA parameters	The national guidelines from 2009			
Traffic growth	1.4%per year[8]			
Investments costs:	€2.5	€0.5	€2.5	€0.5
Yearly running cost	€0.28 billion	€**x** billion	€0.28 billion	€**X** billion
Transport model	SAMPERS			
LUTI model	None	None	'Landscapes'	'Landscapes'
Welfare calculations	'Rule of a half' from Sampers output			

In addition to the analyses displayed in Table 1, a third land-use scenario is simulated under the assumption that the Metro was built in the 1950s. This simulation procedure is identical to the land-use simulated without the Metro (see section 3.3), except that the Metro is assumed to have been part of the transport system since 1950s. A third CBA is also performed, identical to the 'CBA with simulated land-use' in Table 1, with the exception that the third land-use is assumed the metro and the tram scenarios.

[8] There are no numbers for traffic growth on the Metro since 1950. We have assumed that it has increased with population growth. On the one hand journey length has increased since 1950 but on the other hand the availability of cars has increased substantially.

The standard Swedish CBA guidelines and modeling tools, including the national forecasting model Sampers, are applied. The LUTI model applied for the land-use simulation is not used for welfare calculations, for reasons discussed in section 3.3. When the simulated land-use pattern is applied it is imported into the transport model, and the same land-use is assumed in the tram and metro scenarios. In both analyses we make the simplifying assumption that the entire Metro system was built and operational in 1956. 1956 is also the assessment year (i.e. the analysis computes and compares the discounted cost and benefit for 1956). 1956 - 2006 is the appraisal period[9]. The transport model is run for the year 2006. This is similar to standard practice where a transport model is usually used for a future year and benefits before and after that future year are derived by applying a linear growth.

3.1 Scenario development

One of the most uncertain and important assumptions in this analysis concerns how the transport system, and in particular the transit system, would have evolved over time had the Metro not been built. Although this is often forgotten or infeasible in practice, the project analyzed in a CBA should always be compared with the best alternative. The most efficient alternative is not easily determined. Moreover, it is far from certain that the best alternative would have been realized had the Metro not been built.

A natural assumption is that the trams that ran before 1950 along the Metro corridors would have been retained and upgraded, had the Metro not been realized. Another alternative, which was also discussed at the time, is that the trams could have been replaced by buses running on the former tram tracks. Since the capacity and speed of trams and buses on separate lanes are comparable, the outcome of the tram and the bus scenarios with respect to the travel times and the congestion facing the travelers are similar and are therefore not evaluated separately. In other words, we make the assumption that the trams would have been renovated had not the Metro been built, but the costs and the benefits of this scenario cannot be distinguished from a scenario where we assume buses instead of trams.

We assume that the trams have half the frequency, one third of the total capacity and half the speed compared to the Metro. These are bound to be approximate assumptions, since in reality they depend on how modern the trams are and to what extent they are mixed with other traffic. As a comparison, the trams in Gothenburg, which are similar to the trams running in Stockholm until 1950, have a frequency of every ten minutes during peak hours. This is less than half the frequency of the Stockholm Metro. The practical capacity per hour is about six times higher for the Stockholm Metro[10] than the trams in Gothenburg. Our assumptions about frequency and capacity of the trams hence tend to be conservative, minimizing the risk of overestimating the benefit of the Metro.

[9] The appraisal period is the period over which the benefits are assumed to be generated.

[10] The maximum number of seats for each departure is about twice as large on a metro train (384 seats) as in a tram (180 seats).

The construction cost per kilometer of a tram line is presently about half that of a metro line in Stockholm (WSP Analysis & Strategy, 2010). However, it is reasonable to assume that the cost of upgrading and renovating the tram would have been lower than the construction cost of modern light rail tracks. For this reason we assume that the construction cost of the tram is about 20% of that of a Metro.

A key question is whether, in the absence of the Metro, more roads would have been built, connecting suburbs and the inner city (built on several islands. The topology and the size of the city suggest not. There is little space to build more bridges within and to/from the inner city, and even if more bridges would have been squeezed in, there is not enough capacity in the inner city to accommodate many more vehicles. For this reason this alternative is neither very likely nor very efficient. Moreover, the road transport system has been much developed in Stockholm since the 1960s, within the city (more bridges) as well as outside the city (bypasses). In this perspective too, additional large investments seem less likely. We have thus not further evaluated the alternative of more road investments as an alternative to the Metro system.

3.2 CBA method and parameters

In all CBA calculations we apply the national CBA guidelines from 2009 (SIKA, 2008). Table 2 presents the most important parameters. We cannot use guidelines from the appraisal year 1956 because there were none. However, in the 2009 guidelines it is assumed that all valuations are constant across time, and hence it should not matter for which year we apply them. Still, the question arises as to whether guideline valuations, including the value of time, are appropriate for the period of 1956-2006. We know almost nothing about the value of time of 1956. The increase in income and the income elasticity of the value of time may, however, give us some indication.

According to the table, the value of time for regional trips was €5.1/h in the 2009 guidelines. In the 2012 guidelines the values of time were based on a new value of time study and adjusted to €6.1/h for transit and €10/h for car (the increase is due to a more appropriate estimation methodology (Börjesson and Eliasson, 2011)). The real incomes (y) have increased 220% between 1956 and 2006 (SCB, 2013) and the income elasticity of the value of time was estimated to 0.2 for transit users and to 0.8 for drivers in the 2008 value of time study. The income elasticity for drivers was 0.5 in the 1994 value of time study (Börjesson et al, 2010).

If we assume that the income elasticity on public transport value of time is 0.5 and the transit value of time 2006 was €6.1/h, the value of time for 1956 would have been €3.4/h. The average value of time over the entire period 1956-2006, weighted with traffic volume, would then be €5.2/h[11]. Hence to apply a value of time of the 2009 guidelines (€5.1/h) seems reasonable.

[11] The average is weighted taking into account that the number of trips in 2006 is twice the number of trips in 1994.

Table 2: Some of the parameters used in Swedish transport-related CBAs. Source: (SIKA, 2008)

Value of time	Private trips <10 km	5.1 €/h
	Private trips >10 km	10.2 €/h
	Business trips	27.5 €/h
Value of human life and injuries	Life	2.23 M€
	Severe injury	0.415 M€
	Slight injury	20 k€
Emissions[12]	Carbon dioxide	0.15 €/kg
	Particles	1 149 €/kg
	VOC	6.8 €/kg
	SO2	33 €/kg
	NOx	3.6 €/kg
General parameters	Discount rate	4%
	Marginal cost of public funds	1.21

The appraisal period is 40 years with an added residual value for larger projects. Here we simplify this by assuming an appraisal period of 50 years and no residual. We assume that the population growth 1950-2006 is the same in all scenarios, on average 1.4% per year. This assumption can be justified since the city of Stockholm is not very dense and does not have a very large population compared to other European urban regions. Furthermore, we follow the guidelines by assuming that the yearly traffic growth in the metro or tram systems has been proportional to the population growth and a discount rate of 4%.

3.3 Land-use scenarios

We use the Land-Use and Transport Interaction (LUTI) model 'Landscapes' (Jonsson, 2009) to get some idea on the influence of the Metro on the land-use development of Stockholm. There are three different land-use scenarios, all for the year 2006: the historically developed current land-use and two land-use scenarios simulated between 1950 and 2006. The first simulated land-use scenario assumes that the Metro was not built, but that the trams that run along the inner parts of the Metro lines had been retained and renovated. The second simulated land-use scenario assumes that the Metro was built in 1950. The land-use differs between the two simulated scenarios because the Metro affects the spatial distribution of the accessibility.

The population increase is still 1.4% per year. The road investments between 1950 and 2006 were added to the network model roughly the year they were introduced. To decrease the number of different network versions, investments were packaged and added in five year increments.

[12] Values depend on geographical area (except for carbon dioxide), among other things on exposure rates. The values relate to the inner city of Stockholm.

The land-use scenarios modeled by 'Landscapes' build on the assumption that the planning has followed market forces, so that single- and multifamily houses are built where it is most profitable, where profits are defined by market clearing prices minus construction cost. The historical land-use will differ from the simulated scenario with the Metro, not only due to model errors and possible changes in preferences, but also because the land-use and residential planning, particularly before the 1990s were strongly influenced by governmental regulations rather than by market forces.

There are two critical assumptions in the land-use simulation that are worth pointing out. First, we have to assume that the preferences in the land-use and transport models, which are based on the behavior of the population of Stockholm in 2004-2006, are valid for the entire period 1956-2006. This may be questioned. Second, we only simulate how the residential market is influenced by the Metro, assuming that the workplace location is unaffected by the Metro. In the simulations the workplace locations develop according to the same historical patterns derived from census data in both the tram and metro scenarios. In 2006, 33% of the workplaces in the Stockholm County were located in the inner city and 71% of all people employed in the inner city commuted to the inner city (www.stockholmsforsoket.se). Hence, with the current residential pattern the labor market of Stockholm is highly dependent on large transport capacities to and from the city center.

It is unlikely that the latter assumptions favor the Metro scenario. Had more workplaces been reallocated to locations outside the inner city (because of lack of capacity in the inner city) the productivity of the highly specialized labor market of Stockholm would have been lower. Moreover, the higher capacity of the Metro has only been fully utilized since around 1980, i.e. the actual traffic volumes on the Metro do not exceed the capacity of the tram until after 1980s, when to a large extent the location pattern of the workplaces was already formed.

We have not used the LUTI model for welfare calculations in the different land-use scenarios. One could argue that a more consistent way of estimating the consumer benefit of the Metro under the assumption that the land-use adapts, would be to compute the welfare gain from the log-sums generated by the LUTI model. That is, the welfare gain would be computed as the difference between the logsum in the scenario with the Metro and the adapted land-use (the first or third land-use) and the logsum with the tram, with the unadapted land-use (the second land-use). To compute welfare effects of land-use changes consistently are, however, seldom feasible in practice and the present study is no exception. The problem is essentially that the cost-benefit analysis relies on a framework assuming that individuals behave microeconomically consistent, and that they maximize utility subject to some long-term stable preferences of goods including travel time and money. The observed joint behavior of individuals and households on the housing and transport market may not be consistent with these basic assumptions - in fact, usually they are not[13]. In the estimation and building of LUTI models, including this one, the ability to reproduce behavior usually has higher priority than micro-economic consistency. This implies that consistent welfare calculations are difficult in the LUTI model.

Using the same land-use in the do-something and do-nothing scenarios in the transport model implies that the effect on the utility due to changed attractiveness of locations will be left out, as discussed by Geurs et al. (2010).

3.4 Wider economic benefits

The existence of agglomeration benefits is well established. Since agglomeration benefits are external to the employees, they are not captured by the consumer surplus (CS), and hence not by standard CBA for a transport investment (Graham & van Dender, 2010, Venables, 2007). Moreover, distortive taxation also implies that the employee only perceives part of an increase in wage rate or working hours. Benefits from a transport improvement are only captured by the CS to the extent that they are perceived by the individual travelers, as pointed out by Forsyth (1980), implying that increased income tax revenues will not be included. Venables (2007) also shows that when there are both distortive taxation and agglomeration benefits, the corresponding external shares of benefits add to each other.

In Swedish appraisal manual, increased agglomeration and tax revenues are assessed for larger investments on a regular basis (but only the agglomeration effects translated into higher wages, not other parts of GDP), but they are not formally added to the CBA. An elasticity-based relationship estimated from the impact on the total change in gross income (y) 1993-2002 from the total change in accessibility (A) 1986-1997 for commuting trips is used. The total gross income increase due to the investment (in this case $\Delta y = y_{metro}$- y_{tram}) is computed. The change in accessibility from a transport investment is calculated from generalized travel costs and traffic volumes computed by the national transport model. In our case y_{metro} is the observed income in 2006 and y_{tram} is the model computed income level, assuming that the Metro had not been built.

Because we keep the total number of workplaces and population size constant in the analysis, the agglomeration effects due to the increase in population are non-existing. Instead we define agglomeration benefits as the increased productivity arising from better accessibility within and to/from the [inner?] city due to improved learning, matching and sharing (Duranton & Puga, 2004).

The overlap between gross income increase Δy and the welfare benefit computed in the transport model is important. Figure 2 demonstrates this overlap. Part of the effect of Δy is already included in the standard CS: workers using part of the travel time savings to take a job further away that is better paid or to work longer hours. The increased tax revenues arising from higher

[13] In this model the value of commuting time is for instance higher in the land-use model than in the transport model (due to lower price sensitivity in the former), indicating a higher willingness to pay for accessibility in the housing market than in the transport model.

incomes are, however, not included in the standard CS and should thus be added. The total income tax in Sweden is on average 0.54% of the gross income, and the labor market benefit due to income tax is thus 0.54yΔ. This part corresponds to the blue bars in Figure 2.

The income increase due to agglomeration effects (due to improved contact between people and companies) represented by the green bar in Figure 2 is also missing from the standard CS. A crux is that the size of the green bar cannot really be distinguished from the total net income increase (0.46yΔ). As a conservative approximation we assume that the income increase due to agglomeration effects is $0.10\Delta y$. Note also that some of the benefits captured in the standard CS are not captured in the income increase, such as better housing and more leisure time.

The British practice (see WebTAG) for calculating wider benefit use an elasticity relationship to compute productivity increases similar to the Swedish. A main difference is that the former does not explicitly discuss the overlap between the wider impacts and the standard CS.

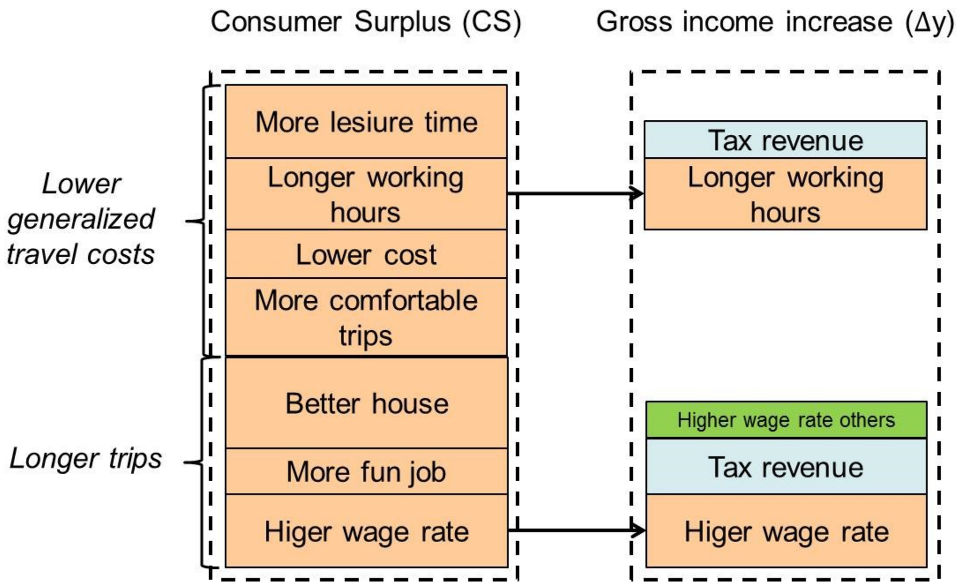


Figure 2: The overlap between consumer surplus computed in the transport model (to the left) and income increase computed on the labor market (to the right).

The elasticity-based relationship is estimated on the Swedish working population (4 million) divided into segments. Each segment is distinguished by age (7 segments), gender (2), ethnic origin (3), educational level (4) and municipality of residence (290). The average income and workplace accessibility is observed for two points in time for each segment, and each segment is treated as one observation in the estimation. The income year 3 (y^3) is regressed on[14] incomes year 1 (y^1), initial accessibility year 0 (y^0), the change in accessibility due to changes in the transport system between year 0 and year

[14] Year 0 is 1985, year 1 is 1993, year 3 is 1996 and year 4 is 2002.

2 (ΔA_T) and the changes in number of work places per zone between year 1 and year 3 (ΔA_E) (the socioeconomic variables are omitted here):

$$\log y^3 = \beta_1 \log y^1 + \beta_2 \log A^0 + \beta_3 \log \Delta A_T + \beta_4 \log \Delta A_E + \cdots, \quad (1)$$

where $\Delta A_T = \frac{\sum_s E_s^1 \exp(\rho c_{rs}^2)}{\sum_s E_s^1 \exp(\rho c_{rs}^0)}$ and $\Delta A_E = \frac{\sum_s E_s^3 \exp(\rho c_{rs}^0)}{\sum_s E_s^1 \exp(\rho c_{rs}^0)}$. E_s is the number of workplaces in zone s, ρ is a negative sensitivity parameter estimated in the transport model. The generalized travel cost, c_{rs}, between zones r and s is computed by the transport model that is used to forecast the traffic effects:

$$c_{rs} = \frac{\sum_{i \in r} \sum_{j \in s} \sum_m T_{ijm} c_{ijm}}{\sum_{i \in r} \sum_{j \in s} \sum_m T_{ijm}},$$

where T_{ijm} is the traffic volume with mode m from zone i to zone j. The notation $i \in r$ means that summation is taken over all traffic zones i belonging to municipality r. The origin and destinations zones of the trips in the transport model have a size of about 0.1-1 km^2.

Basing the relationship on changes over time rather than absolute values of income and accessibility, and controlling for the socioeconomic characteristics (of the segments) reduces endogeneity and confounding problems. The effect is assumed to be lagged, i.e. that the change in income arises after the accessibility change further reduces the endogeneity problems.

The accessibility elasticity on gross income, β_3, is estimated to 0.044, for the Stockholm region (Anderstig et al, 2012). This is well in line with other studies, finding 0.04 (Rice et al., 2006), 0.06 (Ciccone & Hall, 1996) and 0.02-0.05 (Combes et al., 2010). When applying the model to estimate the impact on the incomes from an infrastructure investment all variables except ΔA_T are left unchanged, such that[15]:

$$\frac{y_{metro}}{y_{tram}} = e^{\beta_3 \log \Delta A}, \text{ where } \Delta A = \frac{\sum_s E_s \exp(\rho c_{rs}^{metro})}{\sum_s E_s \exp(\rho c_{rs}^{tram})}. \quad (2)$$

In our case y_{metro} is the observed income in the forecast year 2006 and ΔA is the accessibility increase due to the Metro forecasted by the transport model. E_s is the employment observed in 2006. From this we compute y_{tram}.

[15] The parameter in β_1 is close to unity, implying that the income year 1 has a very strong impact in the incomes year 3. When applying this relationship we are considering the impact of an accessibly increase at a specific point in time. $\beta_1$is this therefore taken to be unity, because this parameter only reflects the income change over time.

4 Models

4.1 The forecasting models

SAMPERS is the national transport model for person trips, covering all types of domestic person trips. The demand models are nested logit models. In the scenarios without the Metro the congestion in the transit system becomes considerable and the capacity constraints must be taken into account in the transport model. The national Swedish transport model uses a version of the EMME/3 assignment model that does not take into account either comfort or capacity constraints in the transit system[16]. To incorporate the capacity constraints in the model, a fixed congestion cost is therefore added to the generalized cost of transit, corresponding to the cost of limited transit capacity. The cost is increased manually and iteratively, until the traffic levels in the transit system do not exceed the maximum capacity of the remaining buses and trains.

SAMPERS does not include any land-use model, so to simulate the effects on the land-use in this study, we use the integrated land-use and transport interaction model (LUTI) 'Landscapes'. 'Landscapes' includes a transport and land-use model that is run iteratively. The transport model is a nested logit model with frequency, mode and destination choice linked to the EMME/2 network assignment model. Both the transport and the land-use model are estimated on a large-scale panel travel survey collected in Stockholm in 2004 and 2006, including moving patterns.

The basic assumption of the land-use model is that new settlements locate where it is most profitable to build in a free market, taking into account location-specific density constraints. The model allocates a subset of the population selected as movers each year. Together with an influx of people, they constitute the participants in the housing market each year t. The households choose housing such that the market clears, i.e. no houses are torn down or uninhabited and each household finds a house. The land-use model is also a nested logit model. On the highest level is the choice on whether to live in a single-family house or a multi-family building. On the lower level is the choice of residential zone i. The utility of locating in zone i for household category k at time t is:

$$U_{ki} = f\left(y_t^k, p_t^i\right) + \theta_k X_{t-1} + \mu_k A_{t-1}^{ki} + \varepsilon_t^{ki},$$

where f is a function of income $\mathrm{y}_\mathrm{t}^\mathrm{k}$ and price p_t^i. X_{t-1}^i describes the characteristics of houses in zone i in the previous year, such as the (fixed) lot size and the cost of living. A_{t-1}^{ki} is the logsum for work tips from the transport model in the previous year. The parameter vectors μ_k and θ_k are estimated from the travel survey and the property prices are determined by the market equilibrium. The housing quality is assumed to be equal across zones.

16 However, for instance Transport for London uses a method called RAILPLAN to take into account discomfort and capacity constraints in the rail system.

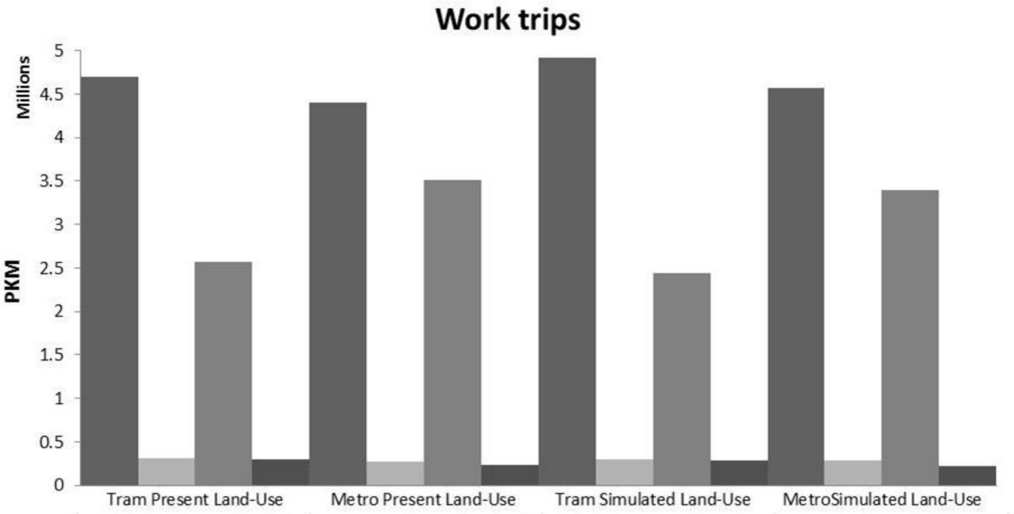
The supply of houses is also modelled by a logit model. The utility of building a new unit of housing in each zone i is given by $V_i = \beta(p_t^i - c_t^i) + \varepsilon_t^i$. Where c_t^i is the construction cost and ε_t^i is a random error. New construction is thus concentrated in zones where the profit is highest, but is also moderated by the density constraints. Each zone is assigned a maximum housing supply, depending on the share of apartment blocks and one-family houses. If demand exceeds supply in a zone, demand is discouraged by higher house prices. Each modelled year, the equilibrium price vector is found by solving a system of equations, such that the housing choices of individuals match vacant housing and new construction.

5 Results

In section 5.1 we compare the traffic situation between the current, with Metro, and the tram scenario, while assuming the historical land-use. In section 5.2 we present the corresponding CBA and in section 5.3 the wider economic impacts. Section 5.4 contains the result of the land-use simulation and its predicted impact on the travel distances, mode shares and CBA.

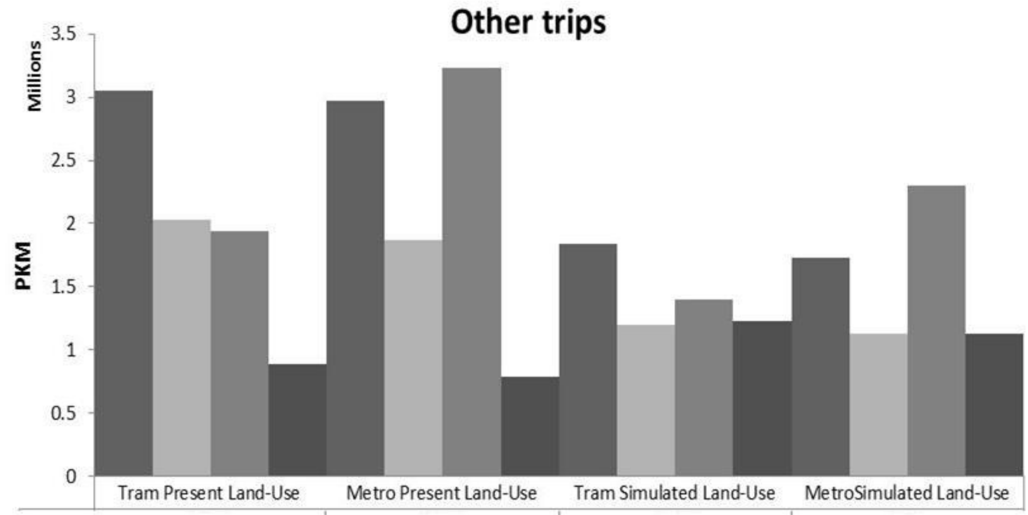
5.1 Traffic effects

The left half of Figures 3 and 4 shows the passenger kilometers travelled (PKM) for different modes and mode shares for work and other trips, in the metro and the tram scenarios with historical land-use. For work trips, the total travel distance by transit (PKM) is 27 % lower in the tram scenario compared to the Metro scenario. The share of trips is only 24% lower, implying that the trip length is slightly longer in the metro scenario. Car driving, both in terms of number of trips and vehicle km travelled (VKT) is 7% lower but the PKM for passengers differ more, 12%. One reason for the small effect on driving is the capacity constraints in the road network implying a considerable latent demand for these car trips if drivers are diverted to transit.



	Tram Present Land-Use	Metro Present Land-Use	Tram Simulated Land-Use	MetroSimulated Land-Use
Driver	47%	43%	50%	45%
Pax	6%	5%	5%	5%
PT	28%	36%	26%	35%
Slow	20%	15%	18%	15%

3: Passenger kilometers travelled (PKM) for different modes (bars) and mode shares (numbers below). Work trips.



	Tram Present Land-Use	Metro Present Land-Use	Tram Simulated Land-Use	MetroSimulated Land-Use
Driver	25%	24%	17%	16%
Pax	15%	14%	11%	10%
PT	15%	22%	16%	23%
Slow	45%	40%	56%	51%

Figure 4: Passenger kilometers travelled (PKM) for different modes (bars) and mode shares (numbers below). Other trips.

A main difference between the tram and the metro scenario is that the PKM for slow modes is 30% higher in the former. Slow mode trips are shorter than car and transit trips (the average trip length is 2.5 km compared to 15-16 km). The average trip length is therefore 5% higher in the metro scenario, implying better matching and higher agglomeration benefits as discussed in section 3.4. The total number of trips is, however, equal in the two scenarios.

The average length of other trips is on average 57% of the work trips and is more often undertaken together with another person. The share of slow modes and car passengers is therefore higher. The total travel distance by transit (PKM) is more affected by the Metro than work trips: it is 40 % lower in the tram scenario compared to the metro scenario. Travel distance for car passenger and slow modes increases 8% and 12%, respectively. The total number of trips is equal in the scenarios. The average trips are 10% longer in the metro scenario, mainly because of the decrease in slow modes.

Figure 5 shows the trip frequency, in total and for different modes, in the tram scenario relative to the trip frequency of the metro scenario in different travel relations. The difference in destination choice appears clearly. The total number of work trips and other trips within the city center and within the suburbs is higher in the tram scenario, while the total number of trips to, from, and through the city center is lower.

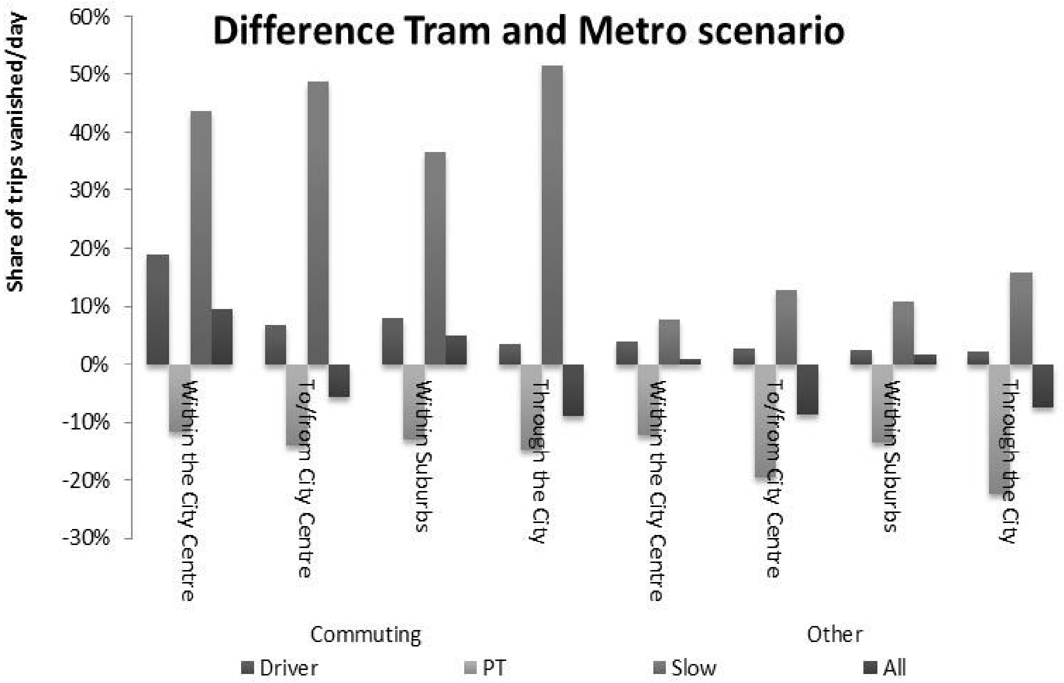


Figure 5: Trip frequency, in total and for different modes (Car Driver, Transit, Slow modes and all trips), in the tram scenario relative to the metro scenario for trips in different relations.

5.2 CBA

The first column of Table 3 summarizes the CBA with the current land-use pattern and shows a net benefit-cost ratio (BCR) of 6.5. The predominant benefit is the CS, and 80% of that stems from increased transit capacity produced by the Metro. This underscores the need to take into account capacity constraints in appraisal when evaluating investments such as the Metro. It also underscores that the major benefit of a metro compared to a tram or buses does not stem from the shorter travel times but from the capacity. More than half of the benefits accrue to travelers with other purposes than commuting, because the former constitutes slightly more than half of the trips in the Metro system.

Table 3: CBA of the Metro. Costs and benefits compare the Metro with the tram alternative. The left column assumes the current land-use and the right the simulated.

	Current Land-Use	Simulated Land-Use
Billon €		
Car travel time savings, work trips	0.1	0.2
Car travel time savings, other trips	0.1	0.1
Transit travel time savings, work trips	1.1	1.0
Transit travel time savings, other trips	1.2	1.1
Increased transit capacity, work trips[17]	5.6	5.4
Increased transit capacity, other trips	5.9	6.1
Sum consumer surplus	**14.0**	**14.0**
Running costs	-1.2	-1.0
Ticket revenue	2.2	2.2
Sum producer surplus	**1.0**	**1.2**
Emissions	0.1	0.2
Accidents	0.2	0.3
Sum externalities	**0.3**	**0.5**
Congestions charges	0.0	0.0
VAT	0.5	0.6
Fuel taxes	-0.2	-0.3
Sum government	**0.3**	**0.3**
Net present value	**15.6**	**15.9**
Net investment cost	-2.0	-2.0
Marginal cost of public funds	-0.6	-0.7
BCR	**5.9**	**6.0**
Wider benefit - income taxation	5.63	
Wider benefit - agglomeration effects	1.04	
Total wider benefit	**6.7**	
BCR (2.5) with ex. labor market benefit	**8.5**	

The second largest benefit is travel time savings for transit travelers. Travel time savings from car traffic are relatively small. This can be explained by the inability of the static assignment procedure to model the queue build-up and blocking of upstream intersections. For traffic passing through the bottlenecks to and from the city center, the volume delay functions are able to predict travel time reductions of less congestion reasonably well, but for traffic further out in the network crossing these intersections, the model is less able to predict the effects on travel times[18]. Where transit is most important (to/from/within the city) the model is thus able to predict the travel time benefits reasonably well, which is important for the accuracy of the forecast of traffic volumes.

[17]This benefit corresponds to the reduced cost of the transit capacity constraints. To calculate the cost of the transit capacity constraints a fixed congestion monetary cost was added to the generalized cost of transit in the transport model, see section 2.1.

[18] These results were found when comparing the model prediction with the real outcome of the introduction of the Stockholm congestion charges (Eliasson et al, 2012).

Externalities due to increases in car use are fairly small in both analyses, and much of it is already internalized by taxes. Producer surplus is positive, i.e. the ticket revenues are larger than operating costs, indicating that the Metro does need subsidies to cover operation costs.

5.3 Wider economic impacts

The ratio of labor market accessibility in the tram and the metro scenarios, ΔA_T, is on average 0.75 for the Stockholm County. The present income in the County is €48.71 billion per year. Thus, using (2) we find that the income would have been $49e^{\beta_3 \log 0.75}$ = € 47.99 billon per year in the situation without the Metro. The yearly income effect of taking out the Metro is thus Δy = 48.71-47.99 = €0.72 billion per year. This is a 1.5% decrease of the total income in the County. The benefit not included in the CS for commuting trips due to income taxation is thus $0.72 * 0.54$= €0.39 billion per year, or €5.6 billion over the assessment period, which equals 83% of the CS for commuting trips (see Table 3). The approximation that agglomeration benefits equal $0.1\Delta y$ adds another €0.07 billion per year, or €1.04 billion over the assessment period, equaling 15 % of the CS for commuting trips. Hence, the wider benefits are €6.7 billion, which is 98% of the CS for commuting trips and 48% of the total CS. The wider benefits are large due a high share of commuting trips and due to the low values of time for commuting applied in the appraisal (reflecting the period 1956-2006), compared to more realistic values of time for 2006. Adding them increases the BCR to 8.5.

5.4 Simulated land-use

The simulated land-use is shown in Figure 6. According to the LUTI model, the region is today more dispersed than if it had been planned according to market forces, given the preferences of the present inhabitants of Stockholm. If the supply of apartments had been higher within the inner city and inner suburbs, more people would have chosen to live in those locations in spite of the higher rents due to higher construction costs.

Table 4 compares the total travel distance by car, mode shares and average trip length between the current situation and the land-use scenario assuming a tram instead of the Metro. The share of trips as a car driver is similar in these two scenarios, but total VKT is lower in the scenario with the denser land-use pattern, because the average trip distance is shorter. The total figures hide an interesting difference between commuting and other trips. For commuting trips, the travel distance by car is 12% *higher* in the simulated land-use scenario with a tram than in the present situation. For other trips, however, the total travel distance by car is 38% *lower*. The Metro, in other words, does reduce car travel for commuter trips because it is competitive at times-of-day and in travel relations where most work trips take place. Relatively more trips with other purposes than commuting have destinations outside the city center and more often take place outside peak hours, making cars more competitive relative to the Metro. The total travel distance by car is therefore higher for these trips in the current, more dispersed, land-use, because the travel distances are longer.

Moreover, the competitiveness of slow modes is substantially higher in the denser land-use, in particular for other trips. The share of slow modes trips is 43% in the denser land-use, compared to 33% in the current situation.

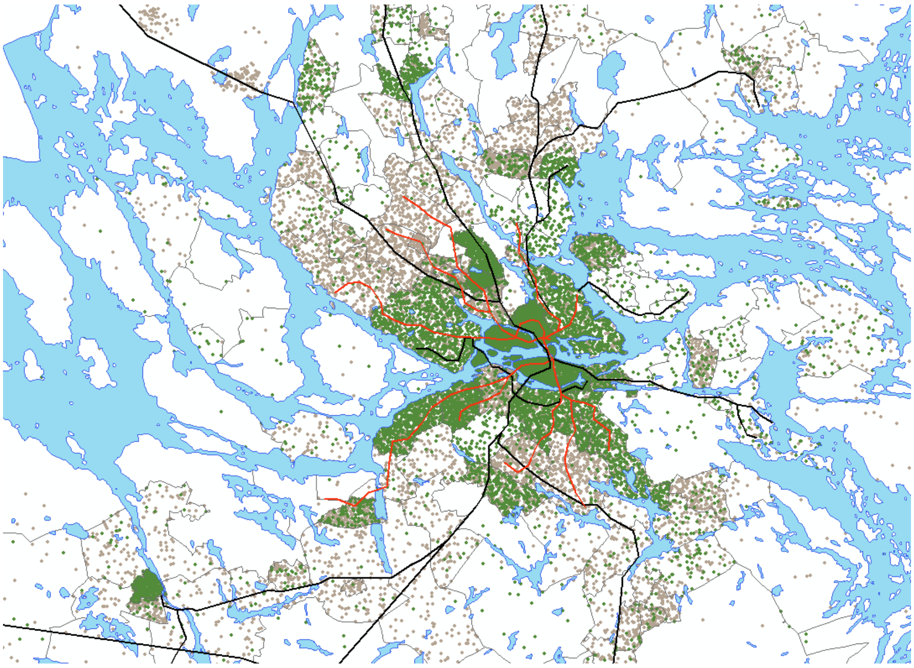


Figure 6: The simulated land-use. The green dots correspond to the simulated population and the gray dots to the present land-use. Each dot corresponds to 100 people.

Figures 3 and 4 include the scenarios with the simulated, denser land-use, to the right. The simulated land-use with the Metro has the lowest VKT (adding work trips and other trips), and a high share of transit and slow modes. The current situation has the highest number of PKM with transit, but not the lowest VKT by car, because the average distance traveled is high. It would appear that the land-use has higher impact on the driving distance and the share of driving trips, in particular for other trips. Comparing the total VKT in the simulated and in the present land-use (both with the Metro) shows 14% lower VKT in the former. Conversely, the VKT is 5% higher in the tram scenario than in the metro scenario (given the present land-use).

For the reasons discussed in section 4.2, we do not calculate the CS under the assumption that the land-use adjusts in response to the Metro. We do, however, carry out the CBA assuming the simulated land-use in both scenarios. The result is found in the right column of Table 3. Interestingly, the consumer benefits of the Metro are very similar assuming the current and the simulated land-use pattern. The main reason is that in both land-use patterns, the capacity benefits are about the same, partly because the workplaces and other destinations are located at the same locations and partly because the share of transit trips (and the absolute number of them) is similar in the two land-use scenarios (see Figures 3 and 4).

Table 4: Total travel distance by car, mode shares and average trip length between in the current situation and the simulated land-use scenario where a tram replaces the Metro.

Infrastructure	Metro			Tram		
	Work	Other	All	Work	Other	All
Vehicle km travelled/day (mill.)	4,4	3,0	7,4	4,9	1,8	6,8
Driver (mode share)	43%	24%	31%	50%	17%	28%
Pax (mode share)	5%	14%	11%	5%	11%	9%
PT (mode share)	36%	22%	27%	26%	16%	19%
Slow (mode share)	15%	40%	31%	18%	56%	43%
Average trip length, driver (km)	16.3	10.8	13.5	15.9	8.7	13.0
Average trip length, pax (km)	9.1	11.9	11.4	9.0	8.6	8.7
Average trip length, PT (km)	15.7	12.6	14.1	15.2	7.3	10.9
Average trip length, slow (km)	2.4	1.7	1.8	2.5	1.8	1.9
Average trip length	13.6	7.7	9.8	13.1	4.6	12.9
# of return trips (mill. per day)	0.59	1. 1	1.7	0.6	1.1	1.7

In the denser land-use the Metro has a larger effect on the destination choice, making transit trips longer and thereby increasing the travel time (this is hidden in the travel time savings in Table 4). The increasing agglomeration benefits seem therefore to be larger in the denser land-use. The travel time benefit for car is larger in the denser land-use due to more congestion in the bottlenecks, but this is still a marginal effect on the total CBA.

For comparison, the land-use is simulated also under the assumption that the Metro was built. Also this land-use is considerably denser than the current, and only somewhat less dense than the land-use simulated with the tram. The accessibility benefit induced by the Metro compared to the tram has thus a limited effect on the land-use. The locations made attractive by the Metro were already attractive with a tram: the inner city and the inner suburbs along tram/metro lines. Moreover, the difference in accessibility created from a metro and a tram were rather similar, in particular before 1980 when the capacity provided for by the Metro was not fully utilized[19].

6 Discussion

The cost of building the Metro was substantially lower in the 1950s than if it had been built now; an expert assessment is that it would cost €11 billion in the present. Assuming this cost the BCR reduces to 1.4. Note that this analysis does not correspond to a cost-benefit analysis of building the Metro 2009 (i.e. with the assessment year 2009), assuming it had not yet been built yet. The forecasting period is 1956-2006 (which had much lower traffic volumes than the period 2006-2056 will probably have), and since the valuations rather correspond to the period of 1956-2006 than the period 2006-2056.

One reason for the low construction cost was that the central parts of the Metro

[19] Hence, one could argue that it would have been better to wait with the building of the Metro. But on the other had the construction cost would then have been higher. It is in general cheaper to build infrastructure early in the history of a city.

coincided with a reconstruction and modernization of central Stockholm. Tunnels were built from the ground down, which is considerably cheaper than to cut the tunnels, and many buildings were torn down. Another reason for the high present cost is high standard, norms and safety. Since it was cheaper to build the Metro system early in the history of the city one could argue that infrastructure should be built as early as possible. On the other hand, building infrastructure early also means that other options are foregone which might prove to be even more beneficial in later years. There is also no guarantee that the costs for infrastructure will continue to grow.

To assess the total benefit of the Metro we have repeated the CBA calculation assuming that there had been no other transit system replacing the aging trams had the Metro not been build (i.e. neither tram nor buses). This assumption would have implied a substantially higher BCR of 11.7 (2.9 with the investment cost €11 billion), which demonstrates the importance of assuming appropriate alternatives to the transport investment under evaluation.

7 Conclusion

The Stockholm Metro was socially beneficial in the 1950s given current national modeling tools and guidelines. Even with an assessed present construction cost, which is about four times the real cost in the 1950s, the Metro would have been beneficial. In conducting an ex-post cost-benefit analysis of such a large and urban project as the Stockholm Metro, we have stretched the CBA models and tools to its limits. Nevertheless we can argue that large (rail) investments never pass a cost-benefit analysis seems to be invalid.

The largest benefit of the Metro is its capacity, making it possible for many people to travel to and from the city center. This provides a strong warning for evaluating this type of project without appropriate transport modeling tools, taking account of capacity constraints in the transit system.

The benefits of the Metro not included in the standard consumer surplus (CS) due to income taxation and agglomeration are 98% of the CS for commuting trips and 48% of the total CS. These additional benefits are large because the Metro is important for commuting and because the values of time for the period 1956-2006 are low compared to the actual values of time for commuters in 2006. Although this is a large increase in benefits, they only imply that the Metro increases the income in the region with 1.5%. In the experiment having no transit system in the no-metro alternative, the income in the County would fall by 3.7%. This is a small but significant difference and consistent with the main conclusion of Fogel (1964) that “no single innovation was vital for the economic growth during the nineteen century”.

Land-use forecast is more uncertain than transport forecasts and must be interpreted with caution. The land-use of Stockholm was simulated from 1950 to 2006, first with a tram replacing the Metro and then with the Metro. The result indicates that Stockholm has developed into a more dispersed region than if the planning would have been determined by the preferences of the current population. The analysis suggests that there is and has been a supply problem: too few houses and apartments have been built in central and semi-central Stockholm due to the planning strategy of building dense residential areas along the metro lines reaching as far as 15 km from the central station. Indeed, the population density of central Stockholm dropped sharply when the modern settlements were planned along the Metro corridors in the 1950s.

It is not the Metro itself that caused the less dense planning, but rather the intense planning effort far from the center. Our land-use simulation indicates that a denser land-use and higher buildings would have been the result of a planning guided by market forces. Moreover, the Metro has a limited impact on the simulated land-use, because the city and inner suburbs are attractive locations in any case. Hence, the land-use impacts from the investment itself seem to be small, but the land-use impacts from planning very large.

The total mileage is 13% lower in the simulated land-use scenario (assuming the Metro in both cases), due to reduced competitiveness of driving and increased accessibility of walking and cycling. The Metro provides a fairly efficient means of transport for commuting to the inner city, but the more dispersed land-use creates longer distances and increased car dependence for non-commuting trips. This is a clear illustration of the disadvantage of regional expansion. A tentative conclusion is therefore that it would have been better not to plan dense land-use and the Metro as far out as 15 km from the central station. The demand for apartments is higher in more central locations, and a denser land-use ultimately also results in lower energy consumption and a lower demand for transport investments. Central Metro lines are in general also more socially profitable lines.

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