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Essays in transport and housing economics

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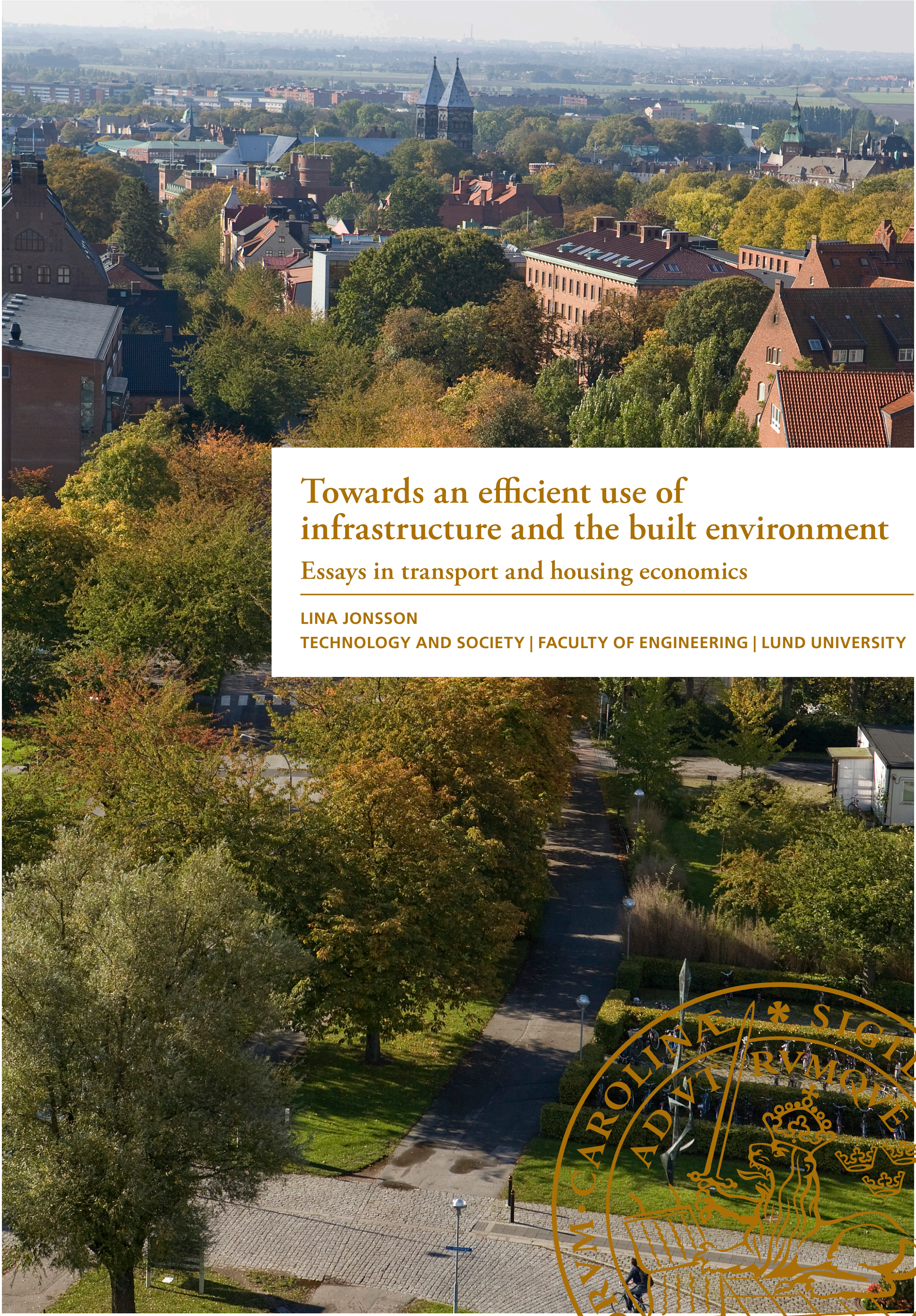

Towards an efficient use of infrastructure and the built environment

Essays in transport and housing economics

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Lina Jonsson

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Abstract

All four papers in the thesis share a common theme: how to achieve an efficient use of infrastructure and the built environment. In the presence of externalities, pricing according to the (short-run) marginal cost is one answer on how this can be achieved and the first two papers estimates parts of the marginal cost of traffic.

Paper I examines the effect of road and railway noise on property prices. It uses the hedonic regression technique on a Swedish data set that contains information about both road and railway noise for each property, and finds that road noise has a larger negative impact on the property prices than railway noise. This is in line with the evidence from the acoustical literature which has shown that individuals are more disturbed by road than railway noise, but contradicts recent results from a hedonic study on data of the United Kingdom.

Paper II estimates accident risks and marginal costs for railway level crossings in Sweden. The marginal effect of train traffic on the accident risk is used to derive the marginal cost per train passage that is due to level crossing accidents. The results show that both protection device, road type, traffic volume of the trains, and number of persons living nearby the level crossing have significant influence on the accident probability. The cost per train passage varies substantially depending on type of protection device, road type, the traffic volume of the trains, and number of persons living nearby the crossing.

Paper III analyses the attitudes to the Stockholm Congestion Charges in 2007, when the congestion charges had been permanently reintroduced after the trial period in 2006. As expected, low car dependence and good transit supply are associated with high acceptability. But the two most important factors turn out to be beliefs about the charges' effectiveness, and general environmental attitudes. The importance of beliefs and perceptions of the effects of the charges underscores the importance of both careful system design and careful evaluation and results communication.

Paper IV analyses how a property tax reform in Sweden in 2008 that lowered the property tax for especially highly taxed single-family houses and increased the tax on profits from property sales influenced the housing tenure transistion of the elderly. The results show that the probability to exit homeownership for elderly households decreased after the tax reform in 2008. And more importantly, this probability decreased more the larger tax cut the household received. The effect is not only statically significant, it is also of a substantial size.

Key words: Hedonic pricing, Noise, Railway traffic, Road traffic, Congestion pricing, Acceptability, Road user charging, Political economy, Railway, Marginal cost, Accident probability, Level crossings, Housing Economics, Property tax

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Introduction

We live in a world with limited resources, and economics is basically about how we can manage these resources to get the most out of them. We want our resources to be used – but not misused or overused. Infrastructure, in the form of roads and rail, will only contribute to our welfare if used. But the usage also has negative effects like emissions and increased risk of traffic accidents that influence others than those that use the infrastructure. An optimal usage therefore must balance the benefits and costs of traffic, considering both the road and rail users and the rest of society. But to do that we need to know the size of the different cost components. We also need to form policies that makes it possible to make people consider not only their own benefits and costs from their choices but also how these choices affect their neighbours and fellow citizens.

The same view can be placed on land use and the built environment. How can we get the most out of available land and housing stock? And how do our taxes and legislation affect how the housing stock is utilized? These are questions that this thesis tries to shed some light on.

The thesis consists of four articles, three of them focuses on externalities in the transport sector and how these can be handled in order to achieve economic efficiency. The fourth article in the thesis concerns the housing market and how a tax reform in 2008 influenced the housing tenure transitions of the elderly. A common theme in the articles is how to achieve an efficient use of infrastructure. For the use of transport infrastructure, pricing according to short run marginal cost is one answer to the question how this can be achieved. The first two articles estimate parts of this marginal cost, relating to noise and traffic accidents. The third article instead looks at the attitude to pricing road traffic according to the marginal cost of road congestion. In the fourth article I leave the transport sector and instead look at the use of the housing stock. The first three papers are published.

The following papers are included in the thesis:

Table 1. Included papers in the thesis

Number	Title	Authors	Published
I	Property prices and exposure to multiple noise sources: hedonic regression with road and railway noise	Andersson, Henrik Jonsson, Lina Ögren, Mikael	2010 in Environmental and Resource Economics, vol. 45, p. 73-89
II	Marginal costs for railway level crossing accidents in Sweden	Jonsson, Lina Björklund, Gunilla Isacsson, Gunnar	2019 in Transport Policy, vol 83, p. 68-79
III	The unexpected “yes”: Explanatory factors behind the positive attitudes to congestion charges in Stockholm	Eliasson, Jonas Jonsson, Lina	2011 in Transport Policy, vol 18, p. 636-647
IV	Should I stay or should I go – How a Swedish tax reform influenced the residential mobility of the elderly	Jonsson, Lina	---

My contribution to the appended research papers I-IV has varied and is outlined below.

Paper I: The study was initiated by Henrik Andersson and Mikael Ögren as a part of a noise research project in cooperation between economists and acousticians at my former employer the Swedish National Road and Transport Research Institute (VTI). My contribution was mainly focused on the empirical part of the paper, including data processing, model estimation and writing the parts of the article that presents the data, econometric model and the results.

Paper II: A working paper version of the article was written by me in 2011 as part of a research project at my former employer VTI. In that working paper data collection and processing, model estimation, the analysis and writing were performed by me. After I had left VTI the Swedish Transport Administration wanted an update of the estimations using more years of data. Gunilla Björklund then reestimated the models for accidents involving motor vehicles with additional years of data and added new models for accidents involving vulnerable road users. The article included in the thesis is based on this updated version of the paper. In the paper that are included in the thesis Gunnar Isacsson contributed by adding simulations (presented in Appendix). All authors contributed to the analysis and writing of the article as presented in the thesis.

Paper III: The article was initiated by Jonas Eliasson that also provided the data. My contribution was mainly focused on model estimation and presenting the results. The analysis and writing of the article were made by joint forces.

Paper IV: The fourth paper in the thesis is also the paper that was last written, during 2020 and 2021. The paper is based on a research idea that I developed when I realised that the data from the Linda-database, that I as a Phd-student had access to, could help answering questions related to mobility on the housing market. The paper is written solely by me using data from the Linda-database provided by Statistics Sweden.

Disposition

The thesis follows closely the papers included. The next section gives a background focusing on the concept of externalities followed by a brief discussion on data and methods used in the four papers. The following four chapters focus on each one of the four papers and their main themes. The thesis ends with a short summary and a discussion on the contribution from the thesis.

The next section makes a description of the most common externalities that is of interest in welfare analysis in the transport sector. How can we quantify the effect from transport on clean air, silence or traffic safety and how can it be valued?

The more general description of different externalities is followed by a section that looks deeper into the externality of traffic noise. How can we value "peace and quiet" and how do we calculate the marginal cost from road and rail traffic related to noise? This is further described by relating to the first article in the thesis and summarizing the results.

Another important externality in the field of transport economics is accident risk externalities. The second article estimates the marginal cost of rail traffic associated with rail-road level crossing accidents.

Pricing is one way of handling externalities. Both noise and increased accident risks caused by rail traffic can be priced through track charges. Correspondingly, calculations of externalities from road traffic can be used for pricing. The congestion tax is the Swedish policy that is closest to a pure pricing of externalities for road traffic, in this case congestion. Although pricing is an appropriate way of dealing with externalities, implementation has been hampered by low public acceptance. The third article in the thesis analyses how socioeconomic, behavioural and attitudinal factors influenced the attitude to the congestion charge in Stockholm after it was permanently reintroduced in 2007 after a trial period.

This is followed by a discussion on how tax policies can influence choices on the housing market based on the fourth article that analyses how a tax reform changed the choice to leave homeownership for elderly households.

Background

The existence of externalities is a common reason for public interference in a market. Externalities arise when production or consumption by an actor affects others and this impact is not considered in the actor's decisions. In the field of transport, the existence of externalities is one major reason why the public interferes in the form of legislation, pricing or public investments. In the presence of externalities, the prices that individuals (or companies) face will not reflect the full societal price of an action. Thereby the allocation of resources and the action of individuals will not be optimal from a societal point of view.

Much of the literature on externalities in the field of transport concerns negative externalities and how these can be handled, often through pricing. Without pricing the traffic volume will be larger than optimal. However, prices higher than the short run marginal cost will lead to underutilization of the transport infrastructure. From the perspective of efficient infrastructure utilization, the prices for using the infrastructure should neither be too high or too low.

How to quantify and value external effects in transport

To determine how the public should act in the presence of externalities, it is important to quantify how large these external effects are. Evaluating the cost from different externalities is necessary both to be able to evaluate measures to reduce the externality, for example through legislation or public investments, but also to be able to set correct prices. Reducing an externality comes at a cost and this cost needs to be comparable to the benefit it entails to achieve an efficient resource allocation. Thus, two types of information are needed to quantify external costs of traffic. What are the effects and how can these be valued?

The first article in the thesis answers the second question for the externality noise, i.e. how can we value noise disturbances. The second article instead looks into the first question; how is the accident risk at level crossing affected when the train volume increases?

From emissions to costs

The ExternE-project started in the early 1990s with the aim to be the first systematic approach to the evaluation of externalities of energy use.[1] In transportation, externalities related to exhaust emissions are mostly quantified using the Impact-Pathway Methodology as it was developed in the ExternE-project. Figure 1 illustrates the four principal steps that traces the passage of a pollutant or other environmental burden from the emission to the cost, in this example exhaust emissions from vehicles.

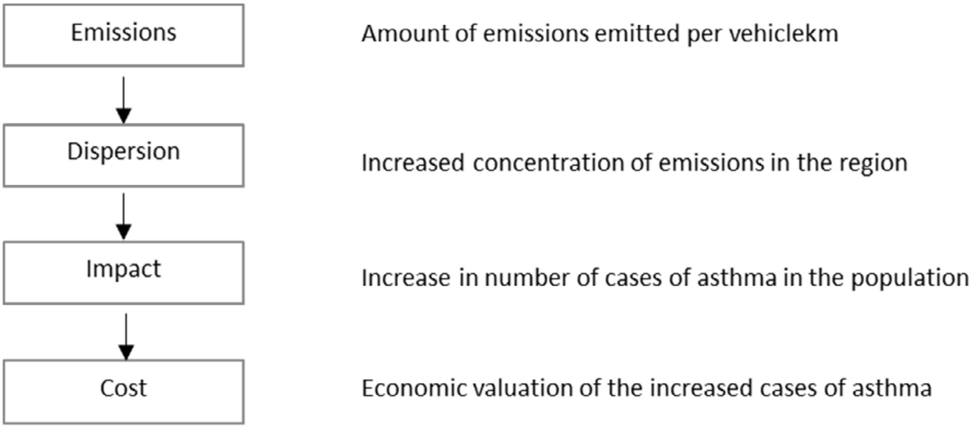

Figure 1. Impact-Pathway Methodology, illustrative example exhaust emissions from vehicles based on (Bickel, o.a., 2005)

Using the Impact-Pathway Methodology as illustrated in Figure 1 makes it clear that the impact from one extra vehicle kilometre differs depending on where the kilometre is driven. How the emissions disperse and the population density (and their valuations) at the place where the emission finally impacts people and nature affects the impact and the cost. This site dependence is important for both air pollution and noise while emissions of carbon dioxide and other greenhouse gases is not site dependent. Greenhouse gases are persistent in the atmosphere and the effect on global warming is the same irrespective of where the gas is emitted. This means that for greenhouse gases it is possible to use one global value per kg emitted while this is not possible for other pollutants.

The complexity and thereby the data demand for the steps can be very different for different impacts. Impacts on the eco-system is perhaps one of the most complex

[1] The ExternE (Externalities of Energy) projects were supported by the European Commission 1991-2005.

and most hard to quantify. For some externalities it is not possible to estimate the costs using the impact-pathway methodology. But the methodology can anyway help by giving a framework for how to describe different steps in the quantification, even though it might not be possible to make calculations in every step.

The impact-pathway methodology visualizes that we need at least two kinds of information to be able to quantify externalities like pollution. How will the activity affect a quantifiable effect like days of illness or the number of fatalities? The second question is how these effects can be valued. What is it worth to reduce one day of illness or one fatality?

Pricing based on the marginal cost

When quantifying externalities for pricing, it is important to have in mind that it is the marginal effect rather that the average effect that matters. In many cases, the marginal effect will depend on the initial level of pollution, noise or traffic. This means that the marginal effect will vary depending on geography, time of day and infrastructure. In most cases it will not be possible to calculate a situation-based marginal effect but the larger the difference is between situations the larger is the need to make proper assumptions on the initial level. If the quantification will be used for governing fees it is even more important. One illustrative example is congestion charging. If the external effect per vehicle km on congestion is used for setting the charge, calculating the mean effect on congestion during the whole day and use as the fee will not help reducing congestion as it will give no incentives for drivers to avoid rush hours where in fact the marginal effect on congestion is the largest.

For governing fees, it is also important to take into consideration what incentives the charging is supposed to give and if the fees are enough differentiated to give these incentives. One example is pricing traffic depending on noise level. Marginal cost pricing implies that vehicles emitting a high level of noise will pay a higher fee than vehicles with a low noise emission. And the difference will be greater the more people that are disturbed. This will give incentives to choose low-emitting vehicles, especially for traffic in densely populated areas. But without a differentiation with respect to noise emissions, a noise charge will not give any incentives for vehicle choice.

Pricing is however not the only way to deal with externalities and knowledge of the marginal cost is valuable also in situations where other policies are taken. Policies in the area of traffic safety involves legislation like speed limits and restricted access for certain vehicle types. I.e. policies that apply to everyone, irrespective of how they value the possibility to arrive sooner or being able to drive a shorter path. When setting speed limits information on the external cost of traffic accidents can contribute in balancing between the value of short travel times and the value of low accident risks.

Obstacles to pricing

The principle of pricing according to short run marginal cost is however not without caveats. The article by Rothengatter (Rothengatter, 2003) and the following comment by Nash (Nash, 2003) gives a rich overview of the issue including the problem with cost recovery. Here I will only give a brief comment on some of the aspects that are relevant for the papers in the thesis.

The marginal cost is in most cases affected by both the characteristics of the infrastructure and the vehicles. While pricing according to a differentiated marginal cost can provide an incentive to the road or rail user to choose a vehicle with properties that give rise to a low marginal cost the pricing regime gives no such incentives to the infrastructure manager in the provision of infrastructure. Rather the opposite. In general, poor infrastructure gives rise to a higher marginal cost per kilometre driven than high quality infrastructure. This is especially true for the costs related to wear and tear but also for costs related to noise, accident risks and congestion.

This is relevant for the second paper in the thesis that estimates how rail traffic flow affects the probability of accidents at level crossings. In the paper separate marginal costs are estimated depending on crossing characteristics. The marginal cost per train passage is found to be higher for crossings with low safety standard than for crossings with the highest safety standard (full barrier), ceteris paribus. Both the choice of protection device and the number of level crossings is under the control of the infrastructure manager, in this case the Swedish Transport Administration. A strict differentiated (short run) marginal cost pricing regime for the track charges would therefore imply that the revenues for the Swedish Transport Administration would decrease with safer level crossings. Strict marginal cost pricing needs to be implemented carefully taking into consideration the incentives given not only to the users of the infrastructure but also to infrastructure managers.

The paradox of paying more for low quality infrastructure than high quality infrastructure can also be expected to affect the acceptability of pricing policies negatively. This hampers implementation of differentiated pricing schemes based on the marginal cost.

Data and methods

All four articles in the thesis are based on a methodology where quantitative data is used to try to say something about a relationship. In the first article, the relationship between noise and house prices is analysed while the second article looks into the relationship between train volumes and the number of level crossing accidents. The third article is based on survey data and analyses stated attitudes towards congestion charges in relation to both socio-economic variables, other attitudes and travel habits. In the fourth article the probability to exit from homeownership is related to a cut in the property tax.

The data sources and types of data differs between the fourth articles and thereby also their strengths and weaknesses. Table 2 presents the type of data used in the four papers together with the method.

Table 2. Data and methods in included papers

Paper	Data	Method
I	Price data for single family houses Property tax assessment Modelled noise levels	Linear regression model
II	Information on rail infrastructure and traffic Information on accidents occurrence	Binary logit model
III	Survey data	Ordered lgbit model
IV	Data from tax assessments	Linear regression model

Even though the four papers are based on different data sources they all have in common that the data is not generated for the purpose of being used in the papers in the thesis. The formulation of models and estimation strategy has therefore been adjusted to available data. This means that we do not have access to all the variables that we would like to have from a theoretical perspective. The fact that the papers also use non-experimental data means that we as researcher do not assign characteristics to the observations. The houses in Paper I has the noise level they have based on their location, not a noise level that we have assigned to them with the aim to optimize our estimation strategy.

Paper I

The first paper in the thesis combines price data on sales of single-family houses with modelled noise levels and information on other house characteristics from the property tax assessment. While the selling price in our data set has few sources of measurement error the variables derived from the tax assessment has a larger degree of discrepancy from the real world. And more important, those characteristics that we have information on are only a part of all the things that matters for how a house is perceived by a buyer. For the noise variables, even if they are modelled correctly giving a correct measurement of the noise levels in dB, the perceived noise level at the time when the house is shown for a potential byer might differ from this. The hedonic method and the data used is though not without weaknesses. We observe real choices but do not fully know which information that are used in making these choices. However, the fact that our estimates of the willingness to pay for a house with a certain noise level is revealed from the real choices made by potential buyers is an advantage compared to studies that relies on the willingness to pay that people state based on hypothetical questions.

Paper II

The second article combines information on rail infrastructure and rail traffic with information from accident records. A major work has been put on data compilation, especially on matching information on crossing characteristics to the right track section. The fact that the study uses information from several years has also brought some difficulties in identifying crossings over time as the location identifier in some cases has changed between years. Although there might still be some crossings that we have not been able to correctly identify as the same crossing for all years, this will not influence the parameters estimated as the panel structure is only utilized for correcting standard errors for clustering based on crossing-id. There is very little variation in traffic flow and crossing characteristics between years for a given crossing and this means that the variation "within" crossings cannot contribute to the estimation of how traffic flow influences the accident probability.

A larger weakness is the lack of information on road traffic flow in the dataset. The accident risk at a crossing is influenced by the traffic flow on both the railway and the road. The proxy-variable approach taken in the article is to use information on road type to capture the influence from road traffic flow. Even though the road type variable is related to the flow the approach does not result in the same accuracy as if we had information on actual traffic flow.

Paper III

This paper is based on a postal survey answered by inhabitants in the municipality of Stockholm in 2007. The survey was not constructed for the purpose of writing the article but was instead conducted by the City of Stockholm. It covers a broad range of environmental issues focusing on the experience of the environment in the respondent's residential area. Only a minor part of the questions is used for the analysis in the article.

The attitudes to congestion charges (our dependent variable) is formulated as a 5-graded response to the question "What is your opinion about the congestion charges" so that we can estimate our models using an ordered-logit model. Our dataset based on survey responses makes it possible to use statistical methods to be able to draw conclusions based on answers from a relatively large number of respondents. However, the use of a postal survey makes it impossible to ask supplementary questions and dig deeper into the underlying reasoning that has led the respondents to ticking a certain box in the questionnaire. How about the paradox of paying more for "bad quality", in this case paying more on a congested road than an un-congested road? Is this an argument that those opposing congestion charges consider important? What information has the respondents considered when forming their belief in the effects on congestion from the charges?

For answering this type of questions, the survey responses do not give enough information. An interview study might have been able to shed some light on this but with the drawback of making it harder to draw conclusions on the attitudes to the congestion charges among the citizens in Stockholm in general.

Paper IV

In this paper register data from tax assessments for a large sample of swedes are used to capture homeownership and socio-economic attributes for elderly households. The focus of the article is the tax reform and how it influenced the decision to exit from homeownership. The database gives detailed information on income and payed taxes including the property tax. The large sample also means that it is possible to look at the probability to exit from homeownership for small subgroups.

However, the dataset lacks information on the individuals own motives for their choice to move or stay. Compared to many other studies on the housing choice of elderly households that are based on survey data, the dataset utilized in paper IV has superior information on household income and payed property tax but no information on how the household perceive their cost of living and their available choices on the housing market.

The value of peace and quiet

Noise causes extensive environmental and health problems and the transport sector is a major source. A large part of traffic noise also occurs in places where people live or work as traffic occurs because of human activity. The cost from noise depends on the extent of noise both in noise level and duration but also how many individuals that are disturbed by the noise. Noise in densely populated areas therefore gives rise to greater costs than corresponding noise in sparsely populated areas.

Noise causes costs for society through the disturbances that noise causes individuals. Sleep disorders can in turn cause health problems and loss of production. The social costs of noise exposure consist therefore of both resource costs in the form of health care, opportunity costs in the form of lost production (both market services, non-market services and lost recreation time) and disutility in the form of other negative influences resulting from noise exposure. This could be disturbances.

The three components are not completely separable and even if it would be possible to separately estimate each of them just adding them up would lead to an overestimation of the total social cost. The resource cost and opportunity cost can be calculated using existing market prices, given that the health effects could be properly calculated. These are the cost of illness. For the disutility on the other hand no market price exists. Instead the valuation of disutility is valued either based on how individuals act on other markets (revealed preferences) or in a hypothetical marked situation (stated preferences). If individuals were fully informed on all the health consequences of noise exposure and also bore all the cost in form of health care and lost production their willingness to pay to avoid noise exposure would include all three components. It is not clear to what degree individuals have knowledge on the likely health consequences of noise exposure. In countries like Sweden a large part of both the resource cost from health care and the opportunity cost in the form of lost production (at least market production) is borne by society rather than the individual.

Evaluating the cost from noise is necessary both to be able to evaluate measures to reduce noise, for example through legislation or public investments in the form of noise protection, but also to be able to correctly price traffic. Noise-reducing measures come at a cost and this cost needs to be compared to the benefits it entails to achieve an efficient resource allocation. A cost benefit analysis (CBA) of policies and projects for noise reductions requires both benefits and costs to be measured in a common metric.

However, a valuation of traffic noise is not only needed to be able to implement CBA. One way to reduce the problems with traffic noise is to get the noise emitter to consider the cost that noise causes in their decision on traffic. An important principle in traffic policy, both in Sweden and within the EU, is that fees for utilizing infrastructure should be based on short-run marginal costs. These marginal costs shall include all the costs incurred by traffic, including the noise costs. To be able to correctly set the fees, monetary values are needed.

Hedonic valuation to capture the disutility cost

Peace and quiet is however not tradable at any observable market. To monetize the social value of changes in noise levels, analysts rely on non-marketed good evaluation techniques, and the technique that dominates is Rosen's hedonic regression method (Rosen, 1974). Hedonic valuation is a form of revealed preference valuation technique. This means that whilst households cannot directly purchase environmental quality like silence in the market, they reveal their preferences for the good through the decisions they make on another market, often the property market.

Most households prefer a home in a less noisy environment, but the supply of such homes is limited. The market will therefore adjust prices on properties in locations with different noise levels so that supply and demand is reconciled, and the market is cleared. The essence of hedonic valuation is to observe the choices made by households in response to these prices.

Estimating implicit prices on one market

Different houses have different characteristics like number of rooms, size of garden, accessibility to workplaces and schools and environmental quality like the level of peace and quiet. This means that housing is an example of a differentiated good. When a household selects a property, they are selecting a specific combination, a bundle, of such characteristics. The price of the property is a function of these characteristics, the hedonic price function. As for most goods the marginal price of more of a characteristic, like peace and quiet, will decline with a higher level due to satiation. This means that the marginal price of a characteristic is not constant but declining.

The derivative of the hedonic price function with respect to one of the characteristics, in this case peace and quiet, is called the implicit price function. The implicit price function illustrates how much more a household need to pay to move to a house with a higher level of peace and quiet, all else equal. The price function is implicit because it cannot be directly observed as peace and quiet is only purchased together with other characteristics in a house. This implicit price function is what is estimated in a first step hedonic regression model. It is estimated by collecting data on property prices and property characteristics on a market and then regress the prices on the housing characteristics.

To compare estimates from different hedonic studies the results are often presented in the form of the Noise Sensitivity Depreciation Index (NSDI). This shows the percentage change in house price brought about by a unit change (1 dB) in traffic noise. If a linear regression model is estimated using the natural log of house price as the dependent variable the NSDI is simply the coefficient for the noise variable. When more complex functional forms are estimated the NSDI varies depending on initial noise level.

Second step

The equilibrium price at a property market will depend on both factors affecting the demand and supply on that particular market. We expect a higher willingness to pay for environmental quality in a market where households are richer compared to a market with poorer households. The supply of a characteristic also effects the implicit price of that characteristic. As a result, the equilibrium price schedule for a housing market reflects the conditions of supply and demand on that market and is therefore unique. The implicit price for peace and quiet will therefore be different for different housing markets.

The household will choose a property where their marginal willingness to pay for extra peace and quiet will equal the implicit price of peace and quiet. Another household with another marginal willingness to pay will choose another amount of peace and quiet that correspond to another point on the implicit price function. The implicit price function gives information on household's marginal willingness to pay and can therefore be used to calculate welfare impacts on marginal changes in housing attributes like peace and quiet on that market.

But in many cases the change in characteristics that we are interested in is non-marginal. A new road will increase traffic noise substantially for nearby properties and an investment in noise barriers might give large reductions in noise. For such large changes the household's marginal willingness to pay at the initial level of peace and quiet will not give a correct measure of the total welfare loss or gain from the full change in noise level. The marginal willingness to pay for a noise reduction is larger the higher the initial noise level is which means that using the marginal willingness to pay at a low noise level (large quantity of peace and quiet) when the noise level increases substantially will underestimate the welfare loss for the household.

The other problem with welfare estimates based on the implicit price function is that these are not transferable between markets. To be able to transfer values between markets we need to estimate the household's demand curve instead. The implicit price function shows one point on this demand curve but to identify the whole curve we need to know the household's choice of the attribute at alternative prices. One way of doing this is by observing how other households on other markets with other implicit prices choose between houses with different characteristics. If we can identify households with the same preferences, often measured by income and socioeconomic characteristics, on other markets facing other equilibrium prices and observe their choices we can use this information to draw conclusions on the shape of the demand curve. This is however hard in practice. One complication arises from the fact that the household when buying a property makes a simultaneous decision on both the quantity of the desired characteristic and the marginal price of that characteristic. This is one reason why the vast majority of empirical studies only estimate the first step in the hedonic method, estimating the hedonic price function and report the implicit prices of different attributes. This first step is enough for measuring marginal changes in a particular market. The first article in the thesis estimates this first step.

Summary of Paper I: Property Prices and Exposure to Multiple Noise Sources - Hedonic Regression with Road and Railway Noise

The first article in the thesis is (Andersson, Jonsson, & Ögren, 2010) who studies the impact of traffic noise on property values. It uses the hedonic regression technique on a Swedish data set that contains information about both road and railway noise for each property to examine the willingness to pay (WTP) to reduce road and railway noise. It is a well-established fact in the acoustic literature that, for the same level of the noise indicator, individuals are more annoyed by road than by railway noise (Miedema & Oudshoorn, 2001). However, a study using the hedonic regression technique in the UK, (Day, Bateman, & Lake, 2007) found that the WTP among property owners to reduce railway noise was higher compared with road noise. This conflicting evidence is interesting since the evidence from the acoustic literature is based on individuals' stated annoyance from different noise sources, whereas the evidence in Day et al. is based on actual decisions by property owners. If road and railway noise is valued differently this has implications on both CBA and pricing. The main contribution of the article is in how it handles the two noise sources and estimates separate noise valuations for road and railway noise.

The empirical analysis is based on a pooled data set for Lerum, a municipality close to Gothenburg, which consisted of two sources; property noise levels from a study on the health effects of traffic noise conducted in Lerum in 2004 and property prices and other attributes (besides the noise variables) from the National Land Survey of Sweden. The two variables defining the noise indicators are our variables of main interest. These two variables reflect the equivalent noise levels (LAEq,24h). Since the noise levels are calculated for both rail and road noise for each property, we have access to unusually rich data on noise levels. The noise variables are in the regressions defined by the absolute noise level minus 45, with 0 for levels below 45 dB.

The effect from noise on the property price should be zero when no negative effect is observed, and in our study, we have chosen to use a lower limit of 45 dB. The limit is somewhat arbitrarily determined, but the percentage of persons reporting that they are annoyed by traffic noise is very low below this level.

When choosing the functional form of the hedonic price function, economic theory leaves us without much guidance. Different forms were tested and based on their results, which revealed the necessity of allowing for a flexible price function, and expectations based on evidence from the acoustical literature, our preferred hedonic price function has the following form:

$$P_i = \gamma_0 \prod_{j=1}^{2} f(L_{ij}) \prod_{h=1}^{H} a_{ih}^{\gamma_h} + \varepsilon_i$$

Where $f(L_{ij}) = 1 + \frac{1-b_j-(1-b_j)e^{k_j L_{ij}}}{e^{30k_j}-1}$

The noise variables are given by $L_{ij} = L_{AEq24h} - 45$ (set to zero for negative values, i.e. if noise levels are below 45 dB) with subscript i and j denoting single properties and road (1) and rail (2), respectively. Other property attributes besides the noise variables are given by a_{ih}, and γ , b, and k are the parameters to be estimated. The parameter b corresponds to the maximum effect at the highest noise level 75 dB in the study area and k describes the concavity of the function. In the regression, the parameter k is restricted to be between 0 and 1 and is estimated as,

$k_j = \frac{e^{c_j}}{1+e^{c_j}}$, thus, c is the parameter that is estimated in the regression.

Note that b and k are estimated separately for road and rail noise. Hence this makes it possible to assume not only different maximum effects from road and rail noise, but also different degrees of concavity for the two noise sources. Moreover, to get a more homogeneous sample only properties with a total noise level of at least 50 dB were included.

The Noise Sensitivity Depreciation Index (NSDI) estimates that shows the percentage change in house price brought about by a unit change (1 dB) in traffic noise for four different noise levels based on the regression results are shown in the table below.

Table 3. NSDI for road and railway noise

Level	Road	Rail
55 dB	1.35	0.08
60 dB	1.70	0.28
65 dB	2.19	1.03
70 dB	2.90	4.09

As can be seen in the table, the impact of one more dB increases with the noise level. There is higher degree of concavity (k) for rail noise that leads to lower NSDI values from rail noise than road noise for low noise levels but higher values for very high noise levels. The effect of rail noise on the property prices is lower than the effect of road noise for all noise levels except the highest (70 dB).

The results show that road noise has a larger impact on property prices than railway noise, except for very high noise levels. Our results are in line with the evidence from the acoustical literature that individuals are more disturbed by road than railway noise (Miedema & Oudshoorn, 2001). This is especially interesting since respondents from the study on which the data set is based stated that they were more annoyed by railway than road noise (Öhrström, Skånberg, Barregård, Svensson, & Ängerheim, 2005).

A theoretically consistent measure of welfare estimates for non-marginal changes of the noise levels requires the estimation of the second step of Rosen's hedonic regression technique (Rosen, 1974). Only the first step is estimated in this study, which means that theoretically consistent estimates for non-marginal changes cannot be obtained from our results. However, if the price function does not shift as a result of changes in the noise level, e.g. if the number of properties with a change is small relative to the total market, the price function may be used to calculate the welfare measure (Freeman, 2003). If we assume that WTP studies do not capture the total social cost from noise exposure, then the values from these studies need to be adjusted such that also the health effects of noise are included.

Concluding reflections

The willingness to pay that is estimated in the article cannot directly be used in a cost-benefit analysis as a cost for each noise-exposed person. The calculated price change needs to be recalculated into an annuity and adjusted for the number of household members and the existence of the property tax. For benefit transfer, i.e. if the values from the study in Lerum should be used in other locations and for coming years, the values should take income differences into consideration. Another question is to what degree health effects from noise is considered by the property byers or if they should be added to the estimates from the article. All of this was done and discussed in another paper that is not included in the thesis, namely (Andersson, Jonsson, & Ögren, 2013).

When converting WTP values from the hedonic price study in Paper I into policy values new sources of uncertainty is introduced. The size of the discount rate has a large effect on the policy values and the choice of discount rate is not self-evident. Especially in times of changing interest rates it is unclear what interest rate a buyer of a house in general are using in his or her calculation of future housing costs and therefore how much he or her believes that a more expensive house in a quiet environment will cost per month or year.

The relation between the WTP value revealed on the property market and the health cost of noise is another source of uncertainty when calculating policy values. Are people aware of the negative health effects of noise, and if so, to what degree do they adjust their willingness to pay for the increased risk of cardio-vascular diseases related to noise? The fact that only a part of the health cost is borne by the individual due to public health care and social security systems implies that even if the byers are aware of the health risks, they do not necessarily adjust their willingness to pay fully to incorporate health effects. On the other hand, high risk aversion against negative health effects could mean that the willingness to pay is adjusted more than a risk-neutral average health cost would imply.

What this discussion shows is that estimating the willingness to pay using the hedonic method is only the first step to get policy values that can be used when deciding on how large costs for noise abatement that are reasonable.

The relation between traffic flow and accident risk

Noise is only one of the externalities that traffic leads to. Another important externality is related to traffic injury. The cost of traffic injury consists of both financial costs for medical treatment, lost income and property damage but also the value of lost quality of life. The lost quality of life can be calculated as the willingness to pay for reducing accident risks.

But not all accident cost is external. Depending on the scope of the public welfare system the financial costs are to a varying extent covered by the public sector. In countries like Sweden both medical treatment and a large part of lost production (income) is covered by the public sector. In such countries the major part of financial costs caused by traffic accidents are external to the road user. The value of lost quality of life can on the other hand be seen as internal when it comes to the lost for the road user himself. But a road user can also impose a higher accident risk on others. Elvik (1994) makes a distinction between three different kinds of external costs of traffic injury:

1. System externalities. These are costs that are imposed on society in general and not born by any group of road users. Costs related to medical treatment and social security systems are included in system externalities.
2. Physical externalities or traffic category externalities. These are costs that one group of road users impose on another in crashes involving both groups. In simple words, it is the risk of injuring someone else. This risk differs substantially between different vehicle categories depending on vehicle size. For at truck many more individuals will be injured in accidents involving trucks outside the truck than inside the truck. For pedestrians it is the other way around. In accidents involving pedestrians and other road users, more pedestrians will be injured (and more severely injured) than road users using vehicles.
3. Traffic volume externality. This is the marginal cost of adding one more road user. The traffic volume externality relates to the relationship between traffic volume and the number of accidents and can be both positive and negative. If the external cost of traffic injury should be internalized using governing fees the traffic volume externality is important to take into account as it defines the relationship between the average cost and the marginal cost.

Traffic volume externalities

To be able to design a tax or insurance system that will internalize the traffic accident externality the tax should be set equal to the marginal external cost that a road user imposes on others. To be able to calculate such a tax we need to know the relationship between accident risk and the traffic volume. Besides from the relation between the number of accidents and the traffic volume also the relationship between traffic volume and the severity of the accidents is of interest. With a higher traffic volume, the number of accidents might increase while the severity of the accidents decline as speed slows down in a more congested traffic system. The proportion of the total accident cost that is external varies depending on severity where accidents with only property damage are almost entirely internal while accidents leading to severe personal injuries have a large proportion of external costs. The proportion of total accident costs that are external might therefore vary depending on traffic volume.

Summary of Paper II: Marginal costs for railway level crossings in Sweden

In the second paper in the thesis "Marginal costs for railway level crossings in Sweden" (Jonsson, Björklund, & Isacsson, 2019), the marginal cost associated with rail-road level crossing accidents is estimated focusing on the traffic volume externality, i.e. how the expected accident cost due to collisions between trains and road vehicles at a given crossing will change when an additional train passes the crossing.

The study is motivated by the principle of marginal cost pricing, a keystone in Swedish transport policy. The external marginal costs of level crossing accidents should be reflected in the price paid by train operators. This means that the train operators should be charged for the expected cost due to level crossing accidents that results from driving one more train on the line. The cost of interest here is the cost that without a charge completely falls on the road users or the rest of society and is therefore external to the train operators. Charging the operators for this external marginal cost even though they do not legally bear the responsibility for the accidents is a way of internalizing the effect that train traffic has on the accident risk of the road users. This line of reasoning has a long tradition in road traffic, but it is obviously relevant also to other types of traffic (see for example (Nash, 2003), for a general discussion).

To estimate the marginal cost associated with rail-road level crossing accidents, separate models are estimated in the paper for motor vehicles accidents and vulnerable road user accidents (here, pedestrians and bicyclists). The expected accident cost depends on both the relationship between train volume and accident risk and the expected cost per accident. The relevant accident cost is the cost that falls on the road users and is taken from the official Swedish values of fatalities and injuries used in cost benefit analyses in the transport sector.

Note that the largest part of accident costs in a level crossing pertains to injuries of the driver and passengers in the road vehicle and material damage to the road vehicle. Thus, these costs are primarily borne by the road user. In Sweden and other countries with substantial public funding of health care, costs are also to a large degree borne by the taxpayers. By charging train operators for the expected external marginal cost, train operators will take into account the effect on the accident risk from train traffic. In this way, the train operator and the road user face the full expected marginal accident costs from level crossings and will, in theory, therefore both choose the optimal level of traffic.

In the paper a marginal cost framework is used. It says that the number of accidents where trains are involved is a function of the traffic volume of trains and other explanatory variables, including the traffic volume of motor vehicles at level crossings and crossing characteristics. The models in the paper are estimated with a pooled logit with clustered robust standard errors where each cluster consists of one crossing. Since the variation over time within the same crossing when it comes to train passages is very small, we cannot utilize the panel character of the dataset.

The (external) marginal cost per train passage can be calculated as the marginal effect on the probability multiplied by the expected accident cost, here estimated by the average cost per accident in the sample. Since the marginal effect is crossing specific the marginal cost will also vary depending on traffic volume, protection device and type of road/number of persons living in proximity of the crossing.

This heterogeneity in the estimated marginal cost is displayed in Table 4. The table shows weighted average marginal cost estimates per passage for each combination of road type and protection device where crossings with many passages have a higher weight than crossings with few passages. Because the marginal effect decreases with the number of passages, the differences between the crossings increases when weighting by the number of passages compared to taking an unweighted average across the crossings. The differences between crossings reflect both differences in protection device, road type, and number of train passages.

Table 4. Marginal cost per train passage for different combinations of road type and protection device – based on weighted average traffic and motor vehicle accidents, year 2012 (SEK)

	Full barrier	**Half barrier**	**Light/sound**	**Unprotected**
National/regional	1.12	1.60	17.82	-
Street/other road	0.47	0.62	4.26	3.89
Private road	0.06	0.07	0.43	0.63

Notes. SEK 1 ≈ EUR 0.1

The paper is an example on how marginal accident costs can be estimated, in this case for level crossing accidents. The results show that the probability of an accident increases with the train traffic volume and that the marginal costs differ substantially between different road types and between different protection devices. Based on this accident cost charges can be set. There may however also be additional cost elements that were not considered here, e.g. the cost of precautional behaviour and non-internalized costs of disturbances in rail traffic.

Concluding reflections

The marginal cost that is estimated in the paper is only related to increased accident risk. However, to avoid accidents, road users take actions that are not costless. This includes slowing down when approaching a crossing but also sometimes changing route to avoid passing a level crossing. Passing a level crossing can also be associated with anxiety and the existence of a level crossing can restrict the mobility of children. If this precautionary behaviour is related to the number of trains that passes the crossing, there exist other marginal cost components that are not included in our estimates. The estimated marginal cost in the paper does not give the complete picture but is a starting point that gives a rough assessment on the size of the marginal cost associated with level crossing accidents related to train traffic.

A second reflection is if the estimated marginal cost should be included in the track charge even though the accidents that occur at level crossings in most cases are caused by some kind of misbehaviour from the road user. Either by not looking for trains, not observing flashing lights or closing barriers, or even by intentionally disregarding warning signs. This is discussed in the paper and the conclusion is that for an optimal choice of activity (in this case the number of trains running the line), the train operators needs to pay for the expected marginal accident costs related to their actions. This is the case even if the road user is legally responsible. However, from the perspective of acceptability, charging train operator (resulting in higher fares) according to costs that arise due to road user misbehaviour can be difficult to motivate.

The attitude to pricing according to external cost

The third article in the thesis relates to the externality of road congestion. However, this article does not estimate the size of the external cost but instead analyses the attitude for pricing according to the external cost. Although taxation of external effects (corrective/Pigouvian taxation) is strongly recommended by economists, implementation is often hampered by low public acceptance. This unpopularity of policies that from an economic perspective are desirable is perhaps the main motivation behind the quite large literature on acceptance for corrective taxes in transport, like congestion charges. Paper III (Eliasson & Jonsson, 2011) follows this tradition.

Why is it then so hard to yield popularity for pricing? One hypothesis is that people in general do not believe that pricing a scarce good, in this case road space, will lead to reduced congestion. Another reason behind the unpopularity could be a belief that congestion pricing will increase travel cost and force a change in travel patterns that are more pervasive that is actually the case when implemented. Both these reasons decrease in importance when the public is familiar with congestion pricing in reality. Paper III analyses the attitudes to the Stockholm Congestion Charges in 2007, when the congestion charges had been permanently reintroduced after the trial period in 2006. This means that the public is familiar with congestion charges, both regarding the effect on road congestion and how their own travel costs changed due to the implementation.

Summary of Paper III: The unexpected ‘‘yes’’ - Explanatory factors behind the positive attitudes to congestion charges in Stockholm

The survey contains several questions regarding the perceived effects of the charging system, both on road congestion and environmental factors like air quality. These perceived effects are highly correlated with the attitudes to the charges. The more positive a respondent is to congestion charges, the stronger is the belief in the beneficial effects of the charges. That own experiences of the benefits will cause a more positive attitude is uncontroversial but the connection between perceived effects and attitudes may also run in the other direction. Both because claiming that congestion charging is ineffective can be a strategic response to justify a negative attitude towards charging and because positive respondents wants to believe that the charges have had beneficial effects. There therefore exists a feedback loop between the perceived effects on system level and the attitudes to the charges, se figure below.

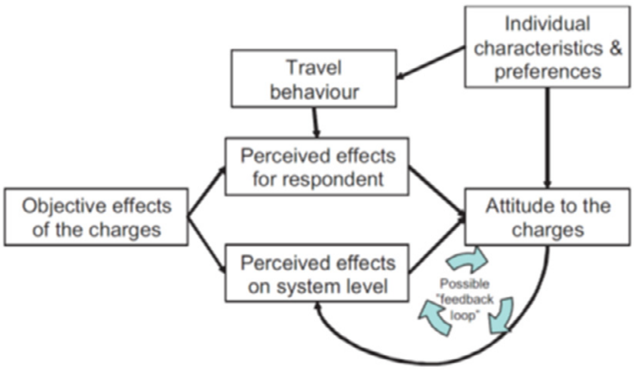

Figure 1. Attitudes to congestion charges

The figure shows that perceived effects, both for the respondent personally and perceived effects on system level together with individual characteristics and preferences influences the attitude to the charges, our dependent variable in the models.

The dependent variable is the 5-graded response to the question ‘‘What is your opinion about the congestion charges’’. This attitude variable is categorical and ordered, so we use an ordered logit model. The parameters in an ordered logit model cannot be interpreted directly. To be able to discuss the importance of the different variables it is not enough to only present the estimated coefficients and significance levels after estimating an ordered logit model. In the paper, the model results are used to forecast attitudes to congestion charges under different circumstances to illustrate the importance of different variables. These different circumstances both relate to travel behaviour, individual preferences and the perceived effects on the system level. The table below show in the first column the Stockholm dataset and the values for seven of the covariates included in the models and in bold the support for the charges (share of very or rather positive). The next four columns show different scenarios where the first two show a situation with less environmental concern and less perceived effects and the last two columns show scenarios with higher car dependence.

Table 5. Model-predicted support for congestion charges under different scenarios.

	Stockholm (%)	Less environmental concerns (%)	Less environmental concerns *and* less perceived effects (%)	Higher car dependence (%)	Very high car dependence (%)
Car availability	55			83	96
Car to work always/most of the time	37			54	83
Rather/very satisfied with public transit	81			48	16
Rather/very interested in env. Issues	72	41	41		
Rather/very important to travel in an env.-friendly way	85	39	39		
Much/somewhat less congestion in the inner city	80		63		
Much/somewhat less congestion on arterials	80		64		
Support for charges (excl. "no opinion")	**67**	**54**	**44**	**59**	**51**

Car dependence matters, but not as much as environmental concern together with perceived effects on congestion. The possible feedback loop between perceived effects and the attitude complicates the analysis, but it is reasonable to assume that even if the perceived effects not only depends on the actual effects, few people would perceive large reductions of congestion if there were no reductions at all. If familiarity with congestion charges should increase the positive attitude to the charges the system also has to be successful in reducing congestion.

Congestion is perhaps the externality where the impact from one more vehicle varies the most depending on time and space. By moving vehicles in time and space, congestion can be greatly reduced without the total traffic flow being particularly affected. A congestion tax system therefore needs to provide incentives not only to reduce traffic in general but more important also provide incentives to change time and destination to times and places with less congestion. For pricing to have major effects on congestion, it is therefore important that the tax system is sufficiently differentiated in both time and space. The fact that attitudes are so much influenced by the perceived effects on congestion shows that it is important that a congestion tax system is sufficiently sophisticatedly designed for obvious effects on congestion to occur. The fact that the congestion tax was first introduced as a trial with an extensive evaluation and the evaluation results was covered in the media has probably contributed to the positive attitudes in Stockholm.

However, framing the Stockholm congestion charges as environmental charges probably also increased popularity due to the high environmental concern in the population. As noted in the article, many people are ready to suffer inconvenience or increased costs for the environment, while much fewer are prepared to suffer to achieve a more economically efficient use of scarce road capacity. If congestion charges are marketed only in the latter way, then it seems unlikely that they will get sufficient public support.

Concluding reflections

It is now 15 years since the Stockholm Trial, when congestion charges were first introduced in Sweden. The survey in Paper III was sent out in 2007, after the trial-period in 2006 and the following referendum and short after the congestion charges was reintroduced in August 2007. At the time when the paper was written, congestion charges was a controversial and much discussed policy in media and among the public in Stockholm. Almost everyone had an opinion. It is 10 years ago the article was published and since then the literature on public acceptance of road charges, and congestion charges in particular, has grown. Even if the congestion charges in Stockholm now are far from the newspaper headlines, congestion charges in general is still a rare policy considering the extent of road congestion in cities around the world, much due to low acceptability. The lessons from Stockholm has perhaps not been so easy to learn from.

The congestion charging system in Stockholm has gone through several changes since 2007. This includes a changed cordon because of new road infrastructure ("Norra länken"), the introduction of charges on the by-pass road "Essingeleden", extensions in time and higher charges. None of these changes has resulted in a public debate that was even a fraction of the debate around 2006. The implemented and planned increases in the charges has been motivated in the debate not so much by the need to handle congestion as a need to find funding for investments in local and regional transport infrastructure (even if the changes has been welfare improving).

But if the congesting charges in 2006 had been communicated as a financing fee to be able to fund investments in roads or public transport, the referendum might not have resulted in the "unexpected yes"? With an increasing share of passenger cars running on electricity instead of fuels, the lost revenue from fuel tax need to be compensated. Road pricing is an appealing substitute if the funding should come from the road users. But it is not self-evident that the positive attitude to congestion charges means that road pricing in the form of a fee per km driven for fiscal reasons would be perceived in the same way as a congestion charge motivated by environmental reasons.

Property tax reform and the decision to exit homeownership

While the third paper examined the attitude to pricing an externality, a popular concept among transport economists but often unpopular among the public, the fourth paper is about a tax that also are much more popular among economists than the common man, namely property tax. In Sweden, the unpopularity of the property tax for single-family houses led to a tax reform in 2008 that lowered the property tax for especially highly taxed single-family houses and increased the tax on profits from property sales. This lowered the cost to stay in a high-valued house and increased the cost of moving. Paper IV analyses how this tax reform influenced the housing tenure transitions of the elderly by comparing households that received a small or non-existent tax cut with household that experienced a large property tax cut.

In the same way that it can be difficult to reach popularity for congestion pricing by emphasizing the gains from more efficient use of road space it is probably also hard to gain popularity for property taxes with arguments focusing on low efficiency losses and reaching a more efficient use of houses. It is also much harder for the citizen to observe the effects of a property tax reform compared to introducing congestion charges where the effect on congestion can be directly visible on the streets. The need to evaluate tax reforms on the housing market is therefore even larger than the need for proper evaluation on changes in pricing regimes in the transport sector.

Summary of paper IV: Should I stay or should I go – How a Swedish tax reform influenced the residential mobility of the elderly

To analyse the tax reform in 2008, a large representative sample of the Swedish population is used where individuals and households can be followed during many years, provided by Statistics Sweden. Variables related to income and payed taxes from the tax assessment together with information on characteristics like age, sex, marital status and number of children living in the household are used. Information on whether someone in the household pays property tax for a single-family house a given year is used to identify homeownership.

Elderly households, in this case households with a family member of at least 65 years old, is the focus of the paper due to the fact that these households are in a phase in their life when we expect them to exit from homeownership to a larger degree compared to younger households. A transition to smaller residences and from homeownership to tenure can both be motivated by life-cycle consumption models and explanations related to changing preferences and health. If the household bought the house many years ago the payments due to interest and amortization are probably small and the property tax therefore represents a larger share of the total housing cost compared to younger households that more recently bought the house. Decreasing tax payments can therefore give a larger effect on the behaviour for the elderly even if the tax cut in absolute numbers is the same for all households.

The tax reform in 2008 decreased the property tax from 1 to 0.75 percentage of the taxable value but also introduced a cap on the property tax that implied that households with a house with a taxable value above 800 000 SEK was taxed to less than 0.75 percentage of the taxable value. The paper uses the fact that the tax reform gave larger tax reductions, both in absolute numbers and in percentage, for higher valued properties to compare the probability to exit homeownership for households before and after the tax reform depending on the size of the tax cut.

The results show that the probability to exit homeownership for elderly households decreased after the tax reform in 2008. And more importantly, this probability decreased more the larger tax cut the household received. The effect is not only statically significant, it is also of a substantial size. This can be seen in the table below where calculations have been made on the predicted probability of exiting homeownership based on estimated parameters in the period before and after the tax reform for households that faced various tax cuts. Calculations are made for three hypothetical households that are identical except that they received different cuts in property tax.

When using the parameters from a model including all years from 2002 to 2013, we see that the probability to exit homeownership is around the same, 4.5-4.6 % per year independent on the taxable value before the tax reform. In the period after the tax reform this probability drops to 1.5 to 2.6 percentage with the largest drop for the household that the received the largest tax cut. We know that the households that had a house with a property value below 800 000 SEK exited homeownership to a very high degree in 2007 while the extra propensity to exit was not so large for those with a higher taxable value. When we instead use the estimated parameters in a model that excludes 2007, we see that the probability to exit homeownership was higher in the period before 2008 for the households with a higher taxable value.

Also, in this case the probability drops the most for the household that received the highest tax cut.

The reduction in property tax cannot explain the whole decrease in the probability to move from a single-family house for these elderly households. As explained earlier other tax changes including a higher tax on profits occurred at the same time. However, the probability to exit homeownership decreases more the larger tax cut the household received and the difference between the three different fictious households are quite large even though the variation in taxable value are far from extreme, those that received a tax cut at 6 000 SEK had a taxable value only three times as a high as those that the received a tax cut of 1 000 SEK.

Table 6. Predicted probabilities to exit homeownership for households 65+ before and after the tax reform

Tax cut	Taxable value (SEK)	Probability to exit before tax reform	Probability to exit after tax reform
All years			
1 000 SEK (below cap)	400 000	4,5%	2,8%
2 000 SEK (on cap)	800 000	4,6%	2,5%
6 000 SEK (above cap)	1 200 000	4,6%	1,5%
Excluding 2007			
1 000 SEK (below cap)	400 000	3,5%	2,6%
2 000 SEK (on cap)	800 000	3,6%	2,3%
6 000 SEK (above cap)	1 200 000	4,4%	1,5%

Both the drop between the period before and after the tax reform and the difference in the size of this drop between the household that received a large tax cut (6 000 SEK) and those with a smaller tax cut (1 000 SEK and 2 000 SEK) is quite large. The difference depending on the size of the tax cut is though not only statistically significant but also with a substantial size.

Concluding reflections

What is then the implications of this? The tax reform was at least in the public debate motivated by a fear that a high property tax forced the elderly out of their homes. After the reform elderly households with highly valued houses decreased their probability to exit from homeownership substantially. In that way the reform did what it was intended to. However, elderly households with a low income and high property value had a reduction in the property tax so that the tax was set to a maximum of 4 percentage of their income both before and after the reform. This group had a lower probability to exit from homeownership than those that payed full property tax before the tax reform and did not decrease their probability to exit as much after the reform as those paying full tax. The tax reform did not affect these households so much as they received a smaller tax cut and changed their behaviour less than those households that payed the full tax.

Fewer elderly households exiting homeownership also means fewer households entering into homeownership as the supply of single-family houses for sale decreases. These households that otherwise would have entered homeownership are probably to a large degree in family-forming age.

But the tax reform did not only have implications on the housing market. Staying in the house makes it harder for the elderly households to consume the wealth that are captured in their homes. This is especially true in Sweden were reverse mortgages are rare and not offered by regular banks. Will these reduced consumption possibilities end up in greater inheritance? And how will that affect the distribution of wealth? The paper does not try to answer these questions but gives a first piece of information on how the tax reform affected the moving behaviour of elderly homeowners in Sweden.

The study cannot fully isolate the effect from the change in property tax from other factors. In addition to the change in property tax, the tax on capital gains from property sales was increased and interest on postponed profits was introduced as a part of the policy package. Also, other changes have occurred since 2007 that had impact on the user cost of single-family housing, both for elderly households and younger households. This includes the introduction of a tax reduction for housing services in 2007 that lowered the cost to gain help with cleaning and garden keeping. Short after the tax change the financial crisis hit the world, including Sweden, having effects both on property prices and unemployment. As a response to rising property prices regulations and recommendations on amortizing requirements and the down payment has also been introduced and strengthened during the period after 2007. Summing up, when discussing the results, one must have in mind that it is a study using non-experimental data with all of the weaknesses it entails. However, for future development on the taxation on property and capital gains from property sales it is important to learn from earlier reforms. The fact that the we can see that the size of the tax cut is related to the change in probability to exit from homeownership is a strong indication that the tax cut decreased the probability to exit even though our non-experimental setting does not rule out that the correlation captured in the regression results at least to a part is due to other factors. This is inevitable using non-experimental methods. However, I believe that the results from the study gives valuable knowledge on how the tax reform changed the moving behaviour of elderly households that are valuable in future policy development.

Summary and contribution

All four papers in the thesis share a common theme: how to achieve an efficient use of infrastructure and the built environment. In the presence of externalities, pricing according to the (short-run) marginal cost is one answer on how this can be achieved and the first two papers estimates parts of the marginal cost of traffic. The results in these papers can be used for policy purposes. On the housing market another principle can guide us - tax neutrality. The fourth paper shows that tax reforms influence people´s behaviour on the housing market and that how we design our tax system matters for how the housing stock is utilized.

In Paper I the willingness to pay for peace and quiet is estimated based on the hedonic method. This is not the first paper to do so, and the innovative part is rather how the flexible functional form allows the two noise sources, road and railway noise, to influence the house prices in different ways, with different degree of concavity. The results are in line with findings in the acoustical literature that people are more disturbed by road than railway noise when the noise level is not too high. However, for very high noise levels the willingness to pay to reduce railway noise is higher than for road noise.

Paper II estimates a marginal cost from railway traffic related to an increased accident risk at level crossings. The research question is motivated by the principle of marginal cost pricing. Very few such studies exist, not only in Sweden but also internationally, and the paper therefore contributes both to a discussion on how and if the increased accident risk that is due to train traffic should be incorporated in track charges and the size of the effect. The marginal cost estimated in the paper is now a part of the official values that are used in Cost-Benefit analysis in the Swedish Transport Sector.[2]

Paper III analyses the attitude to congestion charges in Stockholm. The results show that the belief on the effectiveness of the charges and general environmental attitudes are important factors. At the time of the study few cities had implented congestion pricing and the paper contributed to the understanding of the attitudes in a situation where the citizens were familiar with congestion pricing. The paper do not only conclude what factors that influence the attitudes but also assess the

[2] The ASEK-values, ASEK 7.0, chapter 9.

different factors relative impact. This is done by simulating what the attitudes would have been in a city with different car dependence or different environmental concern among the citizens.

Paper IV analyses a tax reform that lowered the property tax for especially highly taxed single-family houses and increased the tax on profits from property sales. It is shown in the paper that the probability to exit homeownership for elderly households decreased after the tax reform and this probability decreased more the larger tax cut the household received. These results can give valueble input in the public debate on the functioning of the Swedish housing market and hopefully contribute to better policy.

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Paper I

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Property Prices and Exposure to Multiple Noise Sources: Hedonic Regression with Road and Railway Noise

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Abstract This study examines the effect of road and railway noise on property prices. It uses the hedonic regression technique on a Swedish data set that contains information about both road and railway noise for each property, and finds that road noise has a larger negative impact on the property prices than railway noise. This is in line with the evidence from the acoustical literature which has shown that individuals are more disturbed by road than railway noise, but contradicts recent results from a hedonic study on data of the United Kingdom.

Keywords Hedonic pricing · Noise · Railway traffic · Road traffic

JEL Classification C13 · C21 · Q51 · Q53

1 Introduction

It has been suggested that more than 20% of the population of the European Union (EU) are exposed to higher noise levels than considered acceptable (European Commission 1996).

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Noise is an environmental and health problem of major concern in many developed countries, and one of the major sources of noise exposure is the transport sector. Noise from this sector is problematic for, broadly speaking, two reasons: (1) increasing transportation of goods and people means higher noise levels, and (2) since transport is related to human activity and needs, much of it occurs in areas where people live, work, go to school, etc. The latter means that today's urbanization will lead to noise being a bigger problem in the future unless efforts are made to mitigate the problem (Nijland et al. 2003).

Such efforts come at a cost, though, and policies and projects to reduce noise levels need to be evaluated to secure an efficient resource allocation. Benefit cost analysis (BCA) is a powerful tool to evaluate noise abatement, but it requires both benefits and costs to be measured in a common metric. Moreover, the EU has decided that infrastructure charges should be based on short-run marginal costs (European Commission 1998), which has the potential to internalize external effects of traffic. Such charges also require monetary values. To monetize the social value of changes in noise levels, analysts rely on non-marketed good evaluation techniques, and the technique that dominates is Rosen's hedonic regression method (Rosen 1974).

Most studies monetizing noise have focused on road and air noise (Arsenio et al. 2006; Bateman et al. 2001; Garrod et al. 2002; Navrud 2004; Nelson 1982, 2004). This study examines the willingness to pay (WTP) to reduce road and railway noise. It is a well established fact in the acoustic literature that, for the same level of the noise indicator, individuals are more annoyed by road than by railway noise (Miedema and Oudshoorn 2001).[1] However, in a recent study using the hedonic regression technique in the UK, Day et al. (2007) found that the WTP among property owners to reduce railway noise was higher compared with road noise. This conflicting evidence is interesting since the evidence from the acoustic literature is based on individuals' stated annoyance from different noise sources, whereas the evidence in Day et al. is based on actual decisions by property owners.

This study examines how property prices are affected by multiple noise sources, in this case road and railway noise. The aims are: (1) to ascertain whether the findings in Day et al. (2007) are robust for the revealed preference literature or whether the WTP is more in line with the findings in the acoustical literature, and (2) to estimate the WTP to reduce road and railway noise that could be considered in policy implementation. The first aim is of great interest from both a research and policy perspective since it examines how individuals' stated preferences (non-binding) agree with their actual behavior. The second aim is mainly of policy interest, since it examines the need for differentiated values in BCA or infrastructure charges (Andersson and Ögren 2007a,b). We employ the hedonic regression technique on a municipality in the west of Sweden.

The article is organized as follows. Section 2 briefly describes the hedonic regression technique. Sections 3, 4, and 5 contain the data used, the econometric models, and the results. The final section discusses our findings and relates them to other results in the literature.

[1] The evidence also suggests that individuals are more annoyed by air than road noise (Miedema and Oudshoorn 2001).

2 The Hedonic Regression Technique

In his seminal paper, Rosen (1974) showed that in an economy with utility and profit maximizing individuals and firms, the marginal WTP for attributes of composite goods will equal their implicit prices.[2]

Considering the scenario of interest in this study, where our composite good is a property, let L and $\mathbf{A} = [a_1, \ldots, a_n]$ denote noise and a vector of other utility-bearing attributes. The hedonic price function (P) may then be written as

$$P = P(L, \mathbf{A}). \tag{1}$$

Rosen showed that the consumer's WTP for the good will equal its market price. Since, in optimum, the consumer's marginal WTP equals his marginal rate of substitution between the price of the good and any of the attributes, the slope of the price function may be used to determine the consumer's marginal WTP. Focusing on noise, the marginal WTP is, thus, estimated as

$$\text{MWTP} = \frac{\partial P(L, \mathbf{A})}{\partial L}. \tag{2}$$

The information about individuals' preferences from Eq. 2 only reveals the marginal WTP in optimum; it does not reveal the underlying preference structure. To derive the price function and to estimate the marginal WTP using the hedonic regression technique is sometimes referred to as the *first step* of the technique. In the *second step*, where the preference parameters are estimated, the results from the *first step*, together with information on property owners/households, are used. The *second step* enables the analyst to calculate "theoretically consistent" values for non-marginal changes, which was done in Day et al. (2007). In this study only the *first step* is conducted.

3 Data

This study estimates the impact of traffic noise from both railway and roads on property prices in the municipality of Lerum close to Gothenburg in the west of Sweden. Lerum has about 36,000 inhabitants and a population density of 138 inhabitants per km^2. Two major transport routes connecting Gothenburg and Stockholm cross the municipality: the railway line *Västra stambanan* and the motorway *E20*. Figure 1 shows a sketch over the survey area with the two transport routes.

The data set used in this study originates from two sources. The data on the property prices and attributes (besides the noise levels) are from the *National Land Survey of Sweden* and are used for property taxation. The property attributes also contain the geographical coordinates, which are used here to derive geographical variables like neighborhood dummies and distance to nearest train station and highway entrance. The data set covers all the sales of single family houses in the municipality of Lerum from the autumn of 1996 to early 2006. Since the data covers a period of several years, the property prices have been adjusted to the property price index of the Gothenburg region and are shown at 2004 price levels. In the regression,

[2] The hedonic regression technique has been discussed in several articles, books and book chapters (Bateman et al. 2001; Freeman 2003; Haab and McDonnel 2003; Ekeland et al. 2004; Palmquist 2005; Andersson 2008), and we therefore only give a brief introduction to the technique here. For a more comprehensive description of the technique, see references provided or the original source (Rosen 1974).

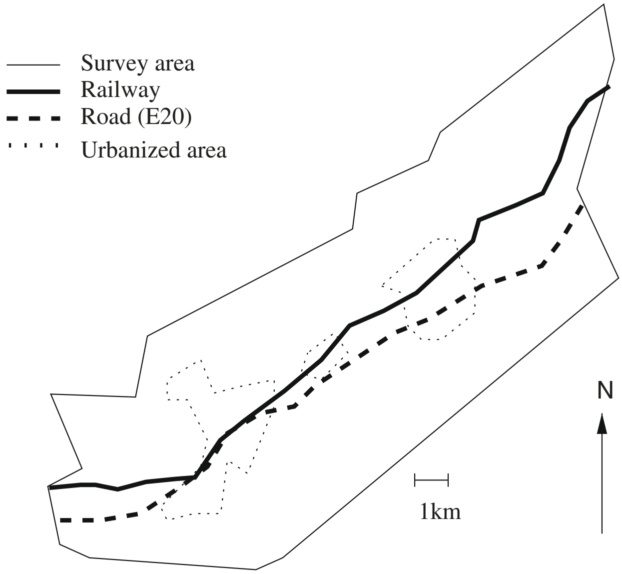

Fig. 1 Sketched map over the research area

the sale closest to January 1 2004 is used for those properties that were sold several times during the period.

Information about noise levels is from a study on the health effects of traffic noise conducted in Lerum in 2004 (Öhrström et al. 2005). Separate noise calculations were made for railway and road noise for all the houses in Lerum.

Descriptive statistics for the different variables are shown in Table 1. The following three sections describe the groups of variables used as explanatory variables in the price equations, followed by a section describing the exclusion criteria used in the regressions.

3.1 Structural Variables

Structural variables define the character of the property, and those used in the regressions are property type, living space and a quality index that is based on a self-reported form that the house owner fills in for the tax assessment. The quality index is based on questions concerning the indoor-quality of the property, for instance the standard of the kitchen, the existence of an open fire place or a sauna, etc. The buildings are categorized as detached, linked by a garage or terraced.

3.2 Geographical Attributes

The geographical variables included in the study are all derived from the coordinates of each property. All the properties are distributed over 11 districts based on their distance to the five commuter train stations in the municipality. The commuter train stations are centrally situated in distinct neighborhoods and the district variables are constructed in a way that divides properties into two groups depending on whether they are 1 km or between 1 and 2 km from the nearest station. For properties more than 2 km from the nearest station a separate district is created, *Country side*. Moreover, a variable measuring the distance to the nearest commuter

Table 1 Descriptive statistics

Variable	Description	Mean value		
		All	$L_{tot} \geq 50\,dB$	$L_{tot} \geq 55\,dB$
Price	Property price in thousand SEK and 2004 price level	1887.215 (655.354)	1917.913 (675.549)	1812.621 (738.747)
Living space	Living space in square meters	128.709 (48.099)	130.144 (47.606)	132.350 (61.515)
Quality Index	Index of indoor-quality	28.934 (5.359)	29.016 (5.517)	28.299 (5.444)
Dist. station	Distance to nearest railway station in km	1.792 (1.222)	1.672 (1.320)	1.585 (1.591)
Dist. entrance	Distance to nearest motorway entrance in km	2.084 (1.033)	1.960 (1.005)	1.802 (0.950)
Road noise	Road noise in dB exceeding 45 dB	5.065 (4.535)	7.566 (4.17)	11.415 (4.895)
Rail noise	Rail noise in dB exceeding 45 dB	1.837 (4.040)	3.005 (4.888)	6.680 (6.597)
Terraced	Dummy equals one if terraced house	0.056	0.063	0.081
Linked	Dummy equals one if house linked by a garage	0.100	0.093	0.051
Detached	Dummy equals one if detached house	0.843	0.844	0.868
Aspen 1	Dummy equals one if <1 km from nearest stn Aspen	0.017	0.026	0.048
Aspen 2	Dummy equals one if 1–2 km from nearest stn Aspen	0.054	0.043	0.015
Aspedalen1	Dummy equals one if <1 km from nearest stn Aspedalen	0.033	0.049	0.102
Aspedalen2	Dummy equals one if 1–2 km from nearest stn Aspedalen	0.096	0.088	0.039
Lerum1	Dummy equals one if <1 km from nearest stn Lerum	0.040	0.063	0.117
Lerum2	Dummy equals one if 1–2 km from nearest stn Lerum	0.230	0.252	0.177
Floda1	Dummy equals one if <1 km from nearest stn Floda	0.023	0.035	0.042
Floda2	Dummy equals one if 1–2 km from nearest stn Floda	0.299	0.246	0.180
Stenkullen1	Dummy equals one if <1 km from nearest stn Stenkullen	0.013	0.019	0.045
Stenkullen2	Dummy equals one if 1–2 km from nearest stn Stenkullen	0.047	0.067	0.153
Countryside	Dummy equals one if >2 km from nearest station	0.149	0.112	0.084
E20 150m	Dummy equals one if within 150 m from motorway	0.082	0.136	0.347
N		1,738	1,034	334

Standard deviations in brackets. For dummies, std.dev.$(x) = \sqrt{\bar{x}(1-\bar{x})}$
EUR 1 = SEK 9.13, www.riksbank.se, 9/16/2008

train station using the road network is included to further capture the accessibility to train and to other community services located close to the train stations. A dummy that equals one for the properties within 150 m from the motorway *E20* is included to control for other disadvantages (or possibly advantages), apart from noise, of living close to a major road, like effects on air quality. To capture accessibility by car, the distance by road to the nearest entrance to the motorway *E20* is also included in the models.

3.3 Noise Indicator

The most commonly used noise indicator is the A-weighted equivalent sound pressure level, which is an energy average over a certain time period, normally 24 h and then denoted $L_{AEq,24h}$. The A-weighting approximates the varying sensitivity of the human ear to different frequencies. The equivalent level is a good indicator of overall annoyance, but for sleep disturbance a better choice is the maximum level, which is normally defined as the maximum noise level occurring during a certain time period. The maximum level is more difficult to predict using calculation methods, and has a complex dependence on the traffic volume since a noisy vehicle may be present even in low traffic conditions (see Sandberg and Ejsmont 2002). We will, therefore, focus on the equivalent level in this study.

In Öhrström et al. (2005) equivalent noise levels ($L_{\mathrm{AEq,24h}}$) were calculated for each property separately for both rail and road noise using the "Nordic methods" (Jonasson and Nielsen 1996; Nielsen 1996). For each residential building the façade with the highest noise level was chosen to represent the property, which meant that the rail noise and the road noise for some properties occurred at different façades. The noise variables were calculated in 2003 and reflected the noise level for that particular year, but the effect of traffic changes is limited if expressed in terms of changed noise level.[3]

The dB-scale used for all noise variables in this study does not have a natural zero point; instead, the zero of the scale is determined by convention (see Sandberg and Ejsmont 2002). The sound pressure level 0 dB corresponds to a sound pressure of 20 μPa, which is roughly the lowest audible level for a tonal sound at a frequency of 1,000 Hz. The total absence of sound is represented by a sound pressure of 0 Pa, corresponding to negative infinity on the dB scale ($-\infty$ dB). For other environmental effects it makes sense to use valuations that vanish when the effect variable becomes zero (for instance, number of particles per m^3 describing air pollution), but the same is not true for noise measured in dBs. The effect should be zero when no negative effect is observed from noise, and in our study we have chosen to use a lower limit of $L_{\mathrm{AEq,24h}} = 45$ dB. The limit is somewhat arbitrarily determined, but the percentage of persons reporting that they are annoyed by traffic noise is very low below this level (Miedema and Oudshoorn 2001). Therefore, the noise variables in our hedonic regressions are defined by the absolute noise level minus 45, with 0 for levels below 45 dB.

3.4 Included Observations

As mentioned above, we assume that equivalent noise levels below 45 dB do not influence the property prices. However, to get a more homogeneous sample we include only properties with a total noise level that is assumed to be disturbing. As thresholds we use two levels, 50 and 55 dB. The first (50 dB) is the official Swedish threshold value, i.e. the official Swedish cost function from noise exposure is zero for noise levels below 50 dB (SIKA 2008). The latter (55 dB) is often used by authorities as a limit value below which no measures are taken to mitigate the noise (Nijland and Van Wee 2005). By using two threshold levels, we also examine how sensitive our regression results are to the chosen level. The threshold level is based on the total equivalent noise level, which is calculated as

$$L_{\mathrm{tot}}(L_1, L_2) = 10 \log(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}}) \tag{3}$$

where $L_j,\ j \in \{1, 2\}$, represent the equivalent noise level in dB from road (1) and rail (2) traffic noise, respectively. When L_1 and L_2 are equal the total level becomes $L_1 + 3$ $(= L_2 + 3)$. If one source is dominant, the other source will have very little influence on the total level ($L_1 \oplus L_2 \approx L_1$ if $L_1 \gg L_2$).

As shown in Table 1, restricting the observations to include only properties with a total noise level of at least 55 dB leads to a reduction of the data set by two thirds compared to using all the observations with a total noise level of at least 50 dB.

[3] Approximately 1 dB for a 30% traffic increase over 10 years.

4 Econometric Model

4.1 Spatial Dependence

The first law of geography states "Everything is related to everything else, but near things are more related than distant things" (Tobler 1970, p. 236). This statement has a bearing on hedonic regressions on property prices as the geographical location of a house is an important element of the good. The concept of near things being more related than distant things is named spatial dependence. Spatial dependence, or spatial autocorrelation, implies that the assumption of independence between observations is violated and is often handled through either a spatial lag or error model (Anselin 1999, 2003). The different models can be hard to distinguish empirically, but they are based on different theoretical grounds. The decision between models in our study is based on diagnostic tests and in terms of fit.

Assuming a linear hedonic model, the spatial lag and error models are defined by (Kim et al. 2003),

$$P = \rho W P + A\beta + \varepsilon, \tag{4}$$

$$P = A\beta + \varepsilon \tag{5}$$

where $\varepsilon = \lambda W \varepsilon + u$, and where W is the spatial weight matrix that describes the correlation structure between observations. If ρ and λ are 0 the spatial lag and error models are reduced to the OLS model. The spatial dependence in the spatial error model in Eq. 5 is assumed to arise from a spatial pattern in omitted variables. Thus, it is appropriate when properties share common amenities that have a spatial pattern and these amenities cannot be controlled for. With the spatial error model the OLS estimator is unbiased but not efficient (Anselin 1999).

The spatial lag model in Eq. 4 assumes that the property price (the dependent variable), in addition to its attributes, is affected by the prices of neighboring houses. This means that the total increase in property value due to a change in the attribute level can be decomposed into a direct and an indirect effect that occurs because, e.g., the increase in the value of the property in question raises the value of neighboring properties, whose increased value in turn raise the value of the property in question further. The reduced form of Eq. 4 shows the effect on the marginal benefit estimate from spatial lag dependence,

$$P = [I - \rho W]^{-1} A\beta + \nu, \tag{6}$$

where β is a vector of the direct effect of the property's own characteristics, $[I - \rho W]^{-1}$ the indirect effect, and $\nu = [I - \rho W]^{-1}\varepsilon$. Hence, based on the spatial lag model the marginal implicit price for attribute l is not given by β_l, but by $\beta_l[I - \rho W]^{-1}$ (Kim et al. 2003).

It is not evident, however, whether the indirect effect should be included when calculating the aggregated social benefit of a change in attribute level. The inclusion of the indirect effect depends on the mechanism behind the influence of neighboring properties (Small and Steimetz 2007). Small and Steimetz (2007) refer to the externality that property values are affected by the values of neighboring houses as either technological or pecuniary. With a technological externality people obtain utility from living close to higher-priced houses; these houses may be better maintained or there may be a status effect. The indirect effect ($[I - \rho W]^{-1}$) then affects utility and therefore is important when estimating the marginal implicit price. Pecuniary externalities arise when the values of surrounding properties do not affect the utility of living in a specific property. A pecuniary effect arises, for instance, when buyers use the prices of surroundings properties as a guide to the value of their property of interest. With pecuniary externalities only the direct effect, estimated by β_l in the spatial lag model, of an amenity change is part of welfare. Here the indirect effect is a transfer and, therefore, welfare neutral.

4.2 Hedonic Price Functions

The noise profiles of road noise and railway noise differ (Miedema and Oudshoorn 2001), and it is therefore reasonable that the influence of road and railway noise on the property price varies. Since our data set contains information about noise levels from both road and railway noise for the properties, it enables us to estimate separately how the different noise sources affect the property prices. Thus, our regressions include separate variables for road and railway noise.

In estimating a relationship between noise and property prices, the choice of functional form is not self-evident. Economic theory leaves us without much guidance (Rosen 1974) and a variety of forms is used in the empirical literature. The semi-logarithmic functional form, where the natural logarithm of the price is assumed to be a linear function of the noise level, is a common choice, but other functional forms such as piecewise linear regressions are also present in the literature (Theebe 2004). We estimate: (1) a semi-logarithmic price function, since it is the model that dominates in the hedonic noise literature, and (2) a function that is designed to have an increasing marginal WTP to reduce the noise level.

The semi-logarithmic model is given by,

$$\ln(P_i) = \beta_0 + \sum_{j=1}^{2} \beta_j L'_{ij} + \sum_{h=1}^{H} \beta_{h+2} a_{ih} + \varepsilon_i \tag{7}$$

where L'_{ij} denotes the noise variables, which are defined as the noise level above 45 dB, subscript i denotes single properties, j denotes road (1) and rail (2) as above, and a_{ih} other property attributes besides the noise variables. The semi-logarithmic model implies a convex relationship between the price of a property and the noise level (when $\beta_j \neq 0,\ \ j \in \{1, 2\}$), i.e. the marginal WTP based on the price function is higher for low noise levels compared to the marginal WTP for high noise levels. However, if the marginal disutility of noise increases with the level, the marginal WTP should increase with the noise level. We, therefore, want to relax the assumption of a convex relationship and estimate a functional form that allows for a concave relationship between the property price and the noise level, i.e. a function where the marginal price discount is increasing with the noise level.

A function that attempts to capture a concave relationship between the property price and the noise level is

$$P_i = \gamma_0 \prod_{j=1}^{2} f(L'_{ij}) \prod_{h=1}^{H} a_{ih}^{\gamma_h} + \varepsilon_i, \tag{8}$$

where γ_h are parameters to be estimated, and where

$$f(L'_{ij}) = 1 + \frac{1 - b_j - (1 - b_j)\, e^{k_j L'_{ij}}}{e^{30k_j} - 1}. \tag{9}$$

The parameter b corresponds to the maximum effect at the highest allowable noise level 75 dB and k describes the concavity of the function. Figure 2a, b shows the functional form for

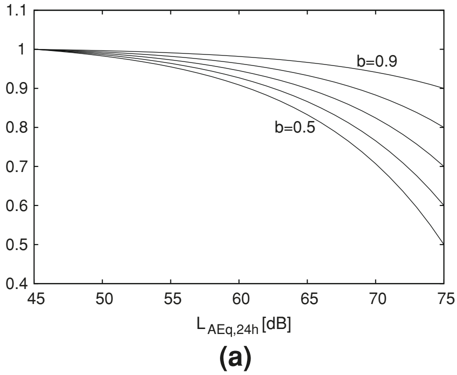

Fig. 2 Influence of the parameters b and k on the price function (9)

different values of b and k, holding the other parameter constant. The parameter k, restricted to be between 0 and 1, is estimated as,

$$k_j = \frac{e^{c_j}}{1 + e^{c_j}}, \tag{10}$$

thus, k is allowed to differ between road and rail noise. Hence, Eq. 8 makes it possible to assume not only different maximum effects from railway and road noise, but also different degrees of concavity for the two noise sources.

5 Results

5.1 Spatial Dependence

The semi-logarithmic model has been tested for spatial dependency using binary and row-standardized distance-based spatial weight matrices. The reason for not testing the concave function for spatial dependence is that methods for incorporating spatial dependence in non-linear regressions have not been developed. The test of spatial dependence was run on each subset, properties with a total noise level of at least 50 or 55 dB based on Eq. 3, and results are shown in Table 2.

The diagnostics in Table 2 are based on a row-standardized inverse distance weight matrix for the larger subset and a binary weight matrix for the smaller subset. The reason for using the binary weight matrix for the smaller subset is because we did not detect any spatial dependence with the matrices based on the inverse distance between properties for this subset. Several band widths were tested, including the largest Euclidian distance in our sample, and the chosen matrices are based on spatial diagnostics and goodness of fit. Based on *Moran's I* we can reject no spatial dependence, and based on the test statistics we conclude that the spatial lag model best describes our data.

5.2 Hedonic Price Regressions

The regression results from the semi-logarithmic models for the two subsets are shown in Table 3. The spatial lag models reveal an improved fit and the spatial lag coefficients (ρ) are statistically significant. We first focus on the the structural variables which are statistically

Table 2 Diagnostic tests for spatial dependency in OLS regression

Test	$L_{tot} \geq 50$ dB			$L_{tot} \geq 55$ dB		
	Statistic	*df*	*p*-value	Statistic	*df*	*p*-value
Spatial error						
Moran's I	2.502	1	0.012	5.224	1	0.000
Lagrange multiplier	0.469	1	0.494	0.271	1	0.603
Robust Lagrange multiplier	8.104	1	0.004	0.456	1	0.500
Spatial lag						
Lagrange multiplier	14.700	1	0.000	11.055	1	0.001
Robust Lagrange multiplier	22.335	1	0.000	11.240	1	0.001
Weight matrix	Inverse distance			Binary		
	Critical distance 10 km			Critical distance 4 km		
	Row-standardized			Not row-standardized		

significant and with the expected signs, with one exception, *Linked*, which is not statistically significant in the regression with only properties exposed to $L_{tot} \geq 55$ dB. Some of the neighborhood dummies are also significant compared to the reference group (*Floda 2*). The prices of properties situated within 150 m from the motorway *E20* are not significantly affected by the motorway, given that the noise level is controlled for. Distance to the nearest train station is not statistically significantly correlated with the property price in any regression, whereas distance to the entrance to the motorway has a positive significant coefficient in one OLS regression but is not statistically significant in the other regressions. Comparing the OLS with the spatial lag models we find that among statistically significant structural and geographical attributes the price effect is reduced in the spatial lag model for most variables. The exceptions are *Living space* which is unaffected, *Quality index* which is only affected in the smaller subset, and *Terraced*, *Stenkullen1* and *Stenkullen2* which have a stronger effect in the spatial lag model in the smaller subset.

The coefficients for the noise variables are our main interest and for both subsets the discount for road noise is higher than for railway noise. We first focus on the OLS regression and using the observations with a total noise level equal to or above 50 dB, the road noise coefficient is highly significant, whereas the railway noise coefficient is significant only on the 10% level. The coefficients imply that a 1 dB increase in road and railway noise is associated with approximately a 1.2 and a 0.4% decrease in property price. Using only the properties with a total noise level equal to or above 55 dB reveals a slightly higher influence of both road and railway noise on the price, 1.7% for road noise and 0.7% for railway noise per dB, both highly significant. The coefficients for road and railway noise are statistically significantly different in both regressions. The fit is slightly better using the data set with only properties with a total noise level equal to or above 55 dB with a R^2 at 0.56, compared to using properties where the threshold is set to 50 dB with a R^2 at 0.51.

The spatial lag model for the sample with a total noise level equal to or above 50 dB shows that there is no change in the direct effect on the price from the road noise, and the coefficient estimate of *Rail noise* is only marginally effected, it changes from −0.004 to −0.003. The coefficient for the railway noise variable is, however, less significant. It is significant at a 10% one-tailed test level ($p-$val $= 0.104$). In the subset with a total noise level equal to or

Table 3 Regression results semi-logarithmic function

Variable	$L_{tot} \geq 50$ dB		$L_{tot} \geq 55$ dB	
	OLS	Spatial lag	OLS	Spatial lag
Living space	0.003***	0.003***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Quality index	0.014***	0.014***	0.018***	0.017***
	(0.003)	(0.003)	(0.004)	(0.004)
Terraced	−0.270***	−0.239***	−0.239***	−0.252***
	(0.024)	(0.026)	(0.040)	(0.039)
Linked	−0.163***	−0.134***	0.002	0.004
	(0.020)	(0.023)	(0.059)	(0.057)
Aspen1	0.272***	0.184***	0.274***	0.191**
	(0.053)	(0.063)	(0.085)	(0.085)
Aspen2	0.175***	0.099**	0.170	0.127
	(0.038)	(0.050)	(0.137)	(0.099)
Aspedalen1	0.257***	0.173***	0.223***	0.018
	(0.048)	(0.055)	(0.080)	(0.090)
Aspedalen2	0.318***	0.235***	0.395***	0.174**
	(0.031)	(0.045)	(0.063)	(0.078)
Lerum1	0.240***	0.166***	0.282***	−0.013
	(0.039)	(0.045)	(0.061)	(0.091)
Lerum2	0.169***	0.121***	0.183***	−0.144
	(0.022)	(0.028)	(0.052)	(0.102)
Country side	0.002	−0.016	−0.236**	−0.120
	(0.052)	(0.054)	(0.114)	(0.110)
Stenkullen1	0.008	0.026	0.073	−0.219**
	(0.076)	(0.076)	(0.107)	(0.111)
Stenkullen2	−0.060	−0.050	−0.153***	−0.439***
	(0.052)	(0.051)	(0.059)	(0.102)
Floda1	0.065	0.064	0.156	0.146
	(0.049)	(0.050)	(0.097)	(0.094)
E20 150m	−0.031	−0.031	0.009	$8 \cdot 10^{-5}$
	(0.030)	(0.029)	(0.043)	(0.040)
Dist. station	−0.007	0.004	0.015	0.037
	(0.017)	(0.019)	(0.026)	(0.028)
Dist. entrance	0.031**	0.014	0.030	0.051*
	(0.014)	(0.016)	(0.032)	(0.030)
Road noise	−0.012***	−0.012***	−0.017***	−0.017***
	(0.003)	(0.003)	(0.004)	(0.004)
Rail noise	−0.004*	−0.003	−0.007***	−0.007***
	(0.002)	(0.002)	(0.003)	(0.002)
Constant	6.688***	2.864*	6.662***	6.213***
	(0.086)	(1.607)	(0.141)	(0.174)

Table 3 Continued

Variable	$L_{tot} \geq 50$ dB		$L_{tot} \geq 55$ dB	
	OLS	Spatial lag	OLS	Spatial lag
ρ		0.517**		$5 \cdot 10^{-4}$***
		(0.217)		$(1 \cdot 10^{-4})$
N	1,034	1,034	334	334
R^2	0.508	0.512	0.561	0.575
Log likelihood	−12.973	−7.942	−21.252	−15.663

Robust standard errors in brackets
Significance levels: * 10%, ** 5%, *** 1%

above 55 dB the spatial lag model has no effect on the coefficient estimates of *Road noise* and *Rail noise*. Hence, if the spatial externality is assumed to be pecuniary the implicit price from the OLS and the direct effect estimated by the spatial lag model are of the same magnitude. However, if the externality is assumed to be technological the marginal implicit price would need to be adjusted with the indirect effect.[4] Since we have no information to determine whether the spatial dependence is pecuniary or technological, and since the direct effect is similar between the OLS and spatial lag model, we choose the conservative approach and assume that the effect is indeed pecuniary.

The concave price function is estimated using nonlinear least-square estimation (Table 4). This function is only estimated for the larger subset due to problem of convergence when the smaller subset was used. This functional form reveals similar results to the semi-logarithmic functional form in terms of signs and statistical significance of the coefficient estimates. Regarding the noise variables, the relevant hypothesis testing for b_j is whether the coefficient is equal to one, since $b_j = 1$ suggests that the price is not influenced by the noise level. We find that b_1 (road noise) is significantly different from 1 while b_2 (rail noise) is not significantly different from 1 at the 10% level. The k-parameter is calculated using the estimates of c_j (see Eq. 10), and is restricted to being between 0 and 1 where a higher value implies a more concave function and a value close to zero implies an almost linear relationship between the noise level and the property price.

The results show that the relationship between property value and rail noise is more concave than the relationship between property value and road noise. This is illustrated in Fig. 3, where the factors $e^{\beta_j L'_{ij}}$ and $f(L'_{ij})$ from the semi-logarithmic (Eq. 7) and concave model (Eq. 8), respectively, are plotted with the estimated parameters. The semi-logarithmic model estimates a stronger negative effect on the price at low noise levels compared to the concave model, and the effect is reversed at high noise levels.

The *Noise Sensitivity Depreciation Index* (NSDI) is often used to compare results from SP and RP noise studies (Bateman et al. 2001; Navrud 2004). It gives the percentage change in property value due to a 1 dB decrease in noise exposure,

$$\text{NSDI} = \left| \frac{\partial P}{\partial L} \frac{100}{P} \right| . \tag{11}$$

[4] The indirect effect, the spatial multiplier, is $(1 - \rho)^{-1}$ and $[I - \rho W]^{-1}$ for a lag model with a row-standardized and binary weight matrix, respectively (Kim et al. 2003).

Table 4 Regression results concave function ($L_{\text{tot}} \geq 50\,\text{dB}$)

Variable	Coefficient	SE
Living space	0.485***	(0.049)
Quality index	0.310***	(0.062)
Terraced	−0.315***	(0.025)
Linked	−0.174***	(0.026)
Aspen1	0.274***	(0.058)
Aspen2	0.218***	(0.055)
Aspedalen1	0.219***	(0.051)
Aspedalen2	0.312***	(0.029)
Lerum1	0.187***	(0.038)
Lerum2	0.153***	(0.027)
Country side	0.063	(0.044)
Stenkullen1	0.079	(0.100)
Stenkullen2	−0.012	(0.079)
Floda1	0.080	(0.057)
E20 150m	−0.012	(0.034)
Dist. station	−0.004	(0.029)
Dist. entrance	0.039	(0.029)
b_1	0.560***	(0.117)
c_1	−3.448**	(1.396)
b_2	0.506	(0.712)
c_2	−1.078	(2.094)
Constant	62.848***	(14.536)
k_1	0.031	(0.417)
k_2	0.254	(0.397)
N	1,034	
R^2	0.949	

Robust standard errors in brackets
Significance levels: * 10%, ** 5%, *** 1%
Subscript $j = \{1, 2\}$ denotes road (1) and rail (2)
$k_j = e^{c_j}/(1 + e^{c_j})$

The semi-logarithmic functional form has the advantage of giving an easily interpretable noise coefficient that can be approximately interpreted directly as the NSDI. This means that the NSDI is constant for all noise levels.

For the concave price function the NSDI is given by,

$$\text{NSDI}(L'_{ij}) = 100 \cdot \frac{f'(L'_{ij})}{f(L'_{ij})} = 100 \cdot \frac{k_j(1 - b_j)e^{k_j L'_{ij}}}{e^{30k_j} - b_j - (1 - b_j)e^{k_j L'_{ij}}} \tag{12}$$

which, since other attributes cancel, only depends on the noise level.[5] Thus, the NSDI of the concave model increases with the noise level as a consequence of the functional form.

Table 5 shows NSDI estimates for the semi-logarithmic models and for different noise levels for the concave model. The higher degree of concavity for rail noise leads to lower NSDI values from rail noise than road noise for low noise levels but higher values for very

5 $f'(L'_{ij}) = -\frac{k(1-b)\,e^{kL'_{ij}}}{e^{30k}-1}$.

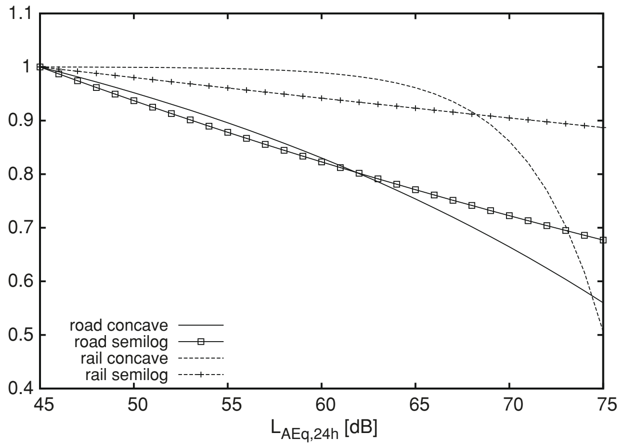

Fig. 3 Estimated price functions for the semi-logarithmic and concave functions for road and railway noise ($L_{tot} \geq 50$ dB)

Table 5 Noise sensitivity depreciation index (NSDI)

Regression model	$L_{tot} \geq 50$ dB		$L_{tot} \geq 55$ dB	
	Road	Rail	Road	Rail
Semi-log				
OLS	1.17	0.36	1.68	0.70
Spatial lag	1.15	0.34	1.69	0.72
Concave				
55 dB	1.35	0.08	–	–
60 dB	1.70	0.28	–	–
65 dB	2.19	1.03	–	–
70 dB	2.90	4.09	–	–

$\text{NSDI} = |(\partial P/\partial L)(100/P)|$

high noise levels. The effect of rail noise on the property prices is lower than the effect of road noise for all noise levels except the highest (70 dB). There are few properties with noise levels above 70 dB, only three properties with road noise at 70 dB or above and three properties with railway noise above 70 dB. This means that the calculated NSDI are based on very few observations for the highest noise levels. Comparing the NSDI for road noise from the semi-logarithmic model with that from the concave model shows that it is lower for all noise levels for the semi-logarithmic model compared with the concave model. The NSDI for railway noise shows more mixed results where the concave model gives lower price discounts for railway noise at low noise levels, but higher discounts at higher noise levels compared to the semi-logarithmic model.

6 Discussion

This study estimates the effect of exposure to road and railway noise on property prices. We have also examined the effect of different functional forms and of the assumption when noise has an effect on the property price (50 or 55 dB). In contrast to the findings in Day et al.

(2007) we show that road noise has a larger impact on property prices than railway noise.[6] Our results are in line with the evidence from the acoustical literature that individuals are more disturbed by road than railway noise (Miedema and Oudshoorn 2001).

We detect spatial dependency in our sample. The coefficient estimates of our variables of major concern, road and railway noise, are not or only marginally affected by the use of spatial lag models compared to OLS. Moreover, the findings between price functions and subsets are robust with expected signs of statistically significant coefficient estimates. Moreover, we show that the chosen threshold level (50 or 55 dB) has an impact on the results. In the semi-logarithmic function the influence of the noise is higher for the 55 dB threshold level for both noise sources.

Our estimates of NSDI for road noise in the semi-logarithmic price function are within the range of previous estimates, e.g. Bateman et al. (2004) reported a range of 0.08–2.22 with a mean value of 0.55. The estimates from the concave function are within the range for noise levels 55, 60, and 65 dB, but above the range for 70 dB, which is true for both noise sources. Overall, we conclude that our NSDI estimates are higher than most of the values reported in Bateman et al. (2004). For railway noise the number of empirical estimates of NSDI is limited; however, Day et al. (2007) report a NSDI of 0.67. Our estimate from the semi-logarithmic model and a total noise level above or equal to 55 dB is close to this estimate, 0.70–0.72, whereas the estimate from the other subsample is lower and the estimates from the concave function varies between 0.08 and 4.09.

A question not addressed in this study is what noise indicator to use. We use the equivalent level for a full 24-h period, $L_{\mathrm{AEq,24h}}$, which is the most commonly used noise indicator. An example of another indicator that better reflects both general annoyance and sleep disturbance is the L_{den} (level day evening night), which has been chosen as the noise indicator in the *Environmental Noise Directive* (European Commission 2002). Baranzini and Ramirez (2005) examined the effect of different noise indicators in hedonic studies and found that the impact was "fundamentally the same, whatever the noise measure used" (p. 643). The above mentioned and examined noise indicators are all scientific indicators. Individuals are, however, assumed to base their decisions on subjective beliefs. Thus, hedonic studies should then be based on subjective and not scientific noise indicators. Baranzini et al. (2008) studied how estimates differed between using a subjective and a scientific noise indicator and found that for moderate and high noise levels (55–75 dB) the scientific noise measure approximated the subjective measure, and that the subjective measure did not improve the hedonic estimation.

A theoretically consistent measure of welfare estimates for non-marginal changes of the noise levels requires the estimation of the second step of Rosen's hedonic regression technique (Rosen 1974; Freeman 1974). Only the first step is estimated in this study, which means that theoretically consistent estimates for non-marginal changes cannot be obtained from our results. However, if the price function does not shift as a result of changes in the noise level, e.g. if the number of properties with a change is small relative to the total market, the price function may be used to calculate the welfare measure (Freeman 2003, p. 379). The official Swedish policy values for noise abatement (SIKA 2008) are based on estimates from a hedonic study on road traffic noise using this approach (Wilhelmsson 2000). The values show a highly convex relationship between the social cost of noise exposure and the noise level, which is a result of the functional form of the price equation in Wilhelmsson (2000). Our study reveals a less convex relationship for road noise, which is in line with Day et al. (2007), who estimated the second step, and thus, a theoretically consistent welfare estimate.

[6] Except at the highest noise levels ($\geq$70 dB) using the concave price function. Note that the estimated price functions at these high noise levels are based on a small number of observations.

Our findings, which contrast with Day et al. (2007) but are in line with the evidence from the acoustical literature (Miedema and Oudshoorn 2001), are especially interesting since respondents from the study on which the data set is based stated that they were more annoyed by railway than road noise (Öhrström et al. 2005). Öhrström et al. (2005) assumed that this was an effect of strategic answers by the respondents, since a new railway track through Lerum was being planned at the time of the survey. The conflicting evidence of stated and revealed preferences for road and railway noise is interesting and highlights the importance of further research.

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Paper II

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Marginal costs for railway level crossing accidents in Sweden

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ABSTRACT

The purpose of the present study is to estimate accident risks and marginal costs for railway level crossings in Sweden. The marginal effect of train traffic on the accident risk is used to derive the marginal cost per train passage that is due to level crossing accidents. The estimations are based on Swedish data from 2000 to 2012 on level crossing accidents, train volume, and crossing characteristics. In this study we estimate the accidents risk for both motorized road traffic and vulnerable road users. As a proxy for road traffic flow we use three categories of road type, and to capture the influences of pedestrians and bicyclists we use information about the number of persons living nearby the level crossing. The results show that both protection device, road type, traffic volume of the trains, and number of persons living nearby the level crossing have significant influence on the accident probability. The marginal cost per train passage regarding motor vehicle accidents is estimated at EUR 0.15 on average in 2012 (price level of 2017). The corresponding number for accidents with vulnerable road users excluding suicides is EUR 0.08 or including suicides EUR 0.50. The cost per train passage varies substantially depending on type of protection device, road type, the traffic volume of the trains, and number of persons living nearby the crossing.

1. Introduction

Railway is in general a very safe transport mode but collisions between road users and trains at level crossings are still a problem due to the, often severe, outcome of the accidents. During the years 2008–2012, 59 level crossing accidents (of which 37 were collisions with motor vehicles) occurred on the Swedish railway network, in all rail operations except metro and tram. As a consequence of these accidents, 34 fatalities and 29 severe injuries occurred among the road users. Corresponding numbers for the years 2003–2007 were 83 accidents (of which 65 were collisions with motor vehicles), leading to 41 fatalities and 47 severe injuries among the road users. Suicides and attempted suicides are not included in these numbers (Trafikanalys, 2013b).

An important keystone in Swedish transport policy is marginal cost pricing. It is therefore important that external marginal costs of level crossing accidents are reflected in the price paid by train operators. This means that the train operators should be charged for the expected cost due to level crossing accidents that results from driving one more train on the line. The cost of interest here is the cost that without a charge completely falls on the road users or the rest of society and therefore is external to the train operators. Charging the operators for this external marginal cost even though they do not legally bear the responsibility for the accidents is a way of internalizing the effect that train traffic has on the accident risk of the road users. This line of reasoning has a long tradition in road traffic (Vickrey, 1968; Newbery, 1988; Vitaliano and Held, 1991; Elvik, 1994; Jansson, 1994; Dickerson et al., 2000; Peirson et al., 1998; Lindberg, 2001, 2005; 2006; Isacsson and Liss, 2016), but it is obviously relevant also to other types of traffic (see for example Nash, 2003, for a general discussion). For an overview of the development of the Swedish accident charges, see Lindberg (2002, 2006).

The purpose of the present study is to estimate the marginal cost associated with rail-road level crossing accidents, i. e. to find out how much the expected accident cost due to collisions between trains and road vehicles at a given crossing will change when an additional train passes the crossing. Separate models are estimated for motor vehicles accidents and vulnerable road user accidents (here, pedestrians and bicyclists). The expected accident cost depends on both the relationship between train volume and accident risk and the expected cost per accident. The relevant accident cost is the cost that falls on the road users and is taken from the official Swedish values of fatalities and injuries used in cost benefit analyses in the transport sector.

As far as we know, no other country, apart from Sweden, has includedthe external marginal level crossing accident cost in the infrastructure charge for railway traffic. Studies on the relationship between

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train traffic and accident risk for road users at level crossings are therefore rare. Instead, calculations on external accident costs for rail is often based on average cost estimations. One example is Delhaye (2017) that motivates the use of average cost by a lack of information on the risk elasticity for rail accidents in the literature.

Another difficulty when comparing our results to other external cost estimates is whether the cost from a level crossing accident that involves both a train and a road user is considered an externality relevant for the railway. In Van Essen et al. (2011), the cost allocation for accident involving several transport modes is based on the responsibility approach meaning that the accident cost from level crossing accidents is attributed to the road user. This differs from how accidents with several vehicles or vehicle categories in road traffic is handled in both Van Essen et al. (2011) and the literature mentioned above. The estimates on marginal external cost of level crossing accidents in this paper have therefore no direct comparison in the literature. This paper, thus, provides empirical evidence that may be informative to railway infrastructure authorities in other countries where marginal cost pricing in the transport sector is considered important.

The paper is organized as follows. In section 2 we outline the main principles of marginal cost pricing of railway level crossing accidents. The main principles provide the key input for the structure of the empirical models outlined in section 3. The data used to estimate the models are presented in section 4 and the empirical results are outlined in section 5. A summary and discussion of the results are provided in section 6.

2. Marginal cost charging and level crossing accidents

Accidents between road users and trains at level crossings are almost always caused by some kind of misbehaviour from the road user. Either by not looking for trains, not observing flashing lights or closing barriers, or even by intentionally disregarding warning signs. It might therefore seem remarkable to put a charge on the train operators that internalizes the costs that otherwise are completely borne by the road users. However, the expected accident cost is external to the train company's decision to run the train; i.e. the managers do not consider the expected accident cost in the decision on traffic. From this perspective, the amount of traffic is not efficient. This is in line with the corresponding reasoning concerning road traffic (for references see the introduction of this study).

More specifically, a theoretical motivation for using marginal cost based charges related to accidents in level crossings can be found in the accident and law literature on how liabilities and costs should be split between involved parties to achieve optimal risk reduction at lowest cost (Shavell, 2004). Accidents between road users and trains at level crossings are bilateral as the actions in the form of care taking and the activity level of both the road user and the train affect the accident risk. Even though it is almost impossible for an engine driver to take any action to avoid a crash when approaching a crossing with a car standing on the track (due to the long stopping distance), the level of activity, i.e. the number of times a train passes a crossing, does affect the accident risk. This means that the train operator has the possibility to reduce the risk by running fewer trains. For the road user, both the effort cost related to additional attention necessary when crossing a railway and the number of times he crosses a railway (the activity level) affect the accident risk.

As Shavell (2004) shows, the rules of liability affect both the behaviour and the chosen activity level of the injurer and the victim. But no liability rule, neither strict liability nor negligence, will by itself lead to an optimal level of activity for both parties in bilateral accidents.[2] A condition for an optimal choice of activity level of both parties is that they both pay for the expected marginal accident costs related to their actions. A charge on trains corresponding to the expected increase in accident costs of road users is a means to internalize the expected external marginal accident cost of train operators.

Note that the largest part of accident costs in a level crossing pertains to injuries of the driver and passengers in the road vehicle and material damage to the road vehicle. Thus, these costs are primarily borne by the road user. In Sweden and other countries with substantial public funding of health care, costs are also borne by the tax payers to a large degree. By charging train operators for the expected external marginal cost, train operators will take into account the effect on the accident risk from train traffic. In this way, the train operator and the road user face the full expected marginal accident costs from level crossings and will, in theory, therefore both choose the optimal level of traffic.

Here we adopt the marginal cost framework proposed by Lindberg (2002, 2006). It says that the number of accidents where trains are involved is a function of the traffic volume of trains (Q_T) and other explanatory variables (X), including the traffic volume of motor vehicles at level crossings (for accidents between trains and motor vehicles):

$$Y = f(Q_T,\ X) \tag{1}$$

where Y represents the number of accidents (in a generic case this should be seen as a vector with rows representing different degrees of injury severity related to the accidents). Related to the accident and each injury severity level is a set of cost components: the willingness-to-pay of the involved user (a), the willingness-to-pay of relatives and friends (b), and system external cost, i.e. mainly medical costs paid by the social security system (c). The marginal cost (MC) with respect to Q_T follows from the total cost (TC):

$$TC = Y(a + b + c) \tag{2}$$

$$MC = \frac{\partial Y}{\partial Q_T}(a + b + c) \tag{3}$$

The willingness-to-pay of relatives and friends (b) is relatively uncertain and is normally not included in calculations of the external marginal cost for traffic accidents (Isacsson and Liss, 2016). Therefore, we will only use the cost components (a) and (c) in our calculations of the marginal costs. Both these components are included in the official Swedish values of fatalities and injuries. These values are 27.7 million SEK[3] for fatalities, 5.1 million SEK for severe injuries, and 0.3 million SEK for light injuries (Trafikverket, 2016, values adjusted to the price level in 2017).

The *external* marginal cost MC^e is calculated as:

$$MC^e = MC - PMC, \tag{4}$$

where MC is the marginal accident cost and PMC is the private marginal cost already internalised by the train operator. The external marginal cost is, thus, the part of total marginal cost relevant to internalize with a charge on infrastructure use of a railway track. The private marginal cost could include delay costs for the operator and any costs due to injuries of the driver or passengers that the operator compensates the passengers for. If we ignore the train operator's own accident cost, the external marginal cost at level crossings is the same as the marginal cost (Lindberg, 2002, 2006). When we henceforth discuss the external marginal cost, we mean the cost that falls on the road user or the rest of society due to injuries when an accident between a train and a road user occurs.

[2] There are two major rules of accident liability. Strict liability implies that the injurer is liable for the harm he causes regardless of whether he was negligent or not. Under the negligence rule, on the other hand, the injurer is only liable if his level of care is below some minimum standard specified by the court.

[3] SEK 1 ≈ EUR 0.1.

3. Empirical models of the accident probality and the marginal cost

As noted in the introduction, the empirical models used in this paper pertain to two different types of level crossing accidents: (i) accidents involving motor vehicles and (ii) accidents involving vulnerable road users (pedestrians and bicyclists). The main reason is to consider potential heterogeneity in the relationship between accidents and traffic flows. Furthermore, vulnerable road users can use crossings where no motor vehicles can cross and the information on traffic flows of motor vehicles and vulnerable road users differ. This implies that we estimate two separate models for the two types of accidents. In what follows we outline a generic model for the two accident types and describe how the included control variables differ between the models. We then describe how we use the estimated models to arrive at estimates of: (i) the marginal cost per train passing the level crossing and (ii) the corresponding marginal cost expressed in vehicle kilometers.

To estimate the marginal costs, we first need an estimate of the accident probability. A suitable count data regression model like the Poisson model or the negative binomial model is a natural choice when modelling the number of events during a given time period. However, during the thirteen years covered in our dataset there is at most one accident per crossing and year, with two exceptions being two crossings with two accidents during the same year.[4] We therefore choose to model the probability that (at least) one accident will occur at a given crossing during a specific year using a logit model.

$$P(y=1|W)=\frac{e^{W'\beta}}{1+e^{W'\beta}}=\Lambda(W'\beta) \tag{5}$$

where $y = 1$ indicates the occurrence of an accident (resulting in at least a personal injury) in that crossing and $y = 0$ otherwise, $W' = (Q_T, X)$ is the set of independent variables, β is the related set of parameters, and $\Lambda(W'\beta)$ is the logistic cumulative distribution function.

In the model of motor vehicle accidents, the set of independent variables includes: the number of passing trains, indicator variables for road type, and indicator variables for protection device. Information on road type is used as a proxy for information on traffic flow of motor vehicles that is missing in our data set. In the model of accidents involving vulnerable road users the set of independent variables includes: the number of passing trains, the number of individuals living in proximity (0–2 km) of the crossing and indicator variables for protection device. Information on the number of individuals living in proximity of the crossing serves as a proxy for information on traffic flow of vulnerable road users that is missing in our data set. The general idea behind this proxy variable is, thus, that individuals living nearby the crossing generate traffic flows of pedestrians and bicyclists.

Note that when analyzing accident frequencies on roads with count data models the length of the road segment is usually entered as a so-called offset variable among the independent variables with parameter equal to one (e.g. Isacsson and Liss, 2016). This serves the purpose of expressing the number of accidents in terms of accidents per kilometer (or some other measure of distance). This is motivated by the fact that the frequency of accidents is necessary larger on longer road segments (all else equal). In addition, the width of the road is also an important control variable in models of road accidents. Level crossing accidents occur, however, at a specific place and the variation in length and width between different crossings is relatively small. We assume that the small differences in the length and the width of the crossing is captured by the control variables for type of protection device and type of road.

The fact that our dataset on crossings is a panel opens up for estimation methods that use the variation in accident risk, traffic and crossing characteristics within the same crossing over time to estimate the effect of traffic on the accident risk. The fixed effects estimator uses a time-invariant individual specific constant to get unbiased and consistent estimates even in the case of unobserved effects that are correlated with the regressors. The downside with the fixed effects estimator is that time-constant variables cannot be included and that the within-variation, the variation within the same crossing over time, is the only source behind the estimation of the effect of train traffic on the accident risk. In cases where the variation over time within the same crossing is very small compared to the variation between crossings the fixed effects estimator is not a suitable alternative. The random effects estimator uses both the variation within a crossing and the variation between crossings and is a good choice if it can be assumed that unobserved individual specific effects are uncorrelated with the regressors. If the variation within a crossing over time is very small the random effects estimator approaches the pooled estimator.

In our dataset the variation over time within the same crossing when it comes to train passages is very small. The fixed-effects estimator is therefore not an appropriate choice. The estimation of a random effects logit model shows that the within-variation is insignificant, i.e. the variation over time within the same crossing is so small that it cannot help explain the variation in accident probability. Due to this fact the models in the paper are estimated with a pooled logit with clustered robust standard errors where each cluster consists of one crossing.

The (external) marginal cost per train passage can be calculated as the marginal effect on the probability multiplied by the expected accident cost, here estimated by the average cost per accident in the sample (C):

$$MC=\partial P/\partial Q_T\times C \tag{6}$$

Since the marginal effect is crossing specific (see equations (7a)-(9a) below) the marginal cost will also vary depending on traffic volume, protection device and type of road/number of persons living in proximity of the crossing. The cost per accident in the sample is estimated from the information available for all years in the sample. The motivation is that the number of accidents in a given year is small and there is some variation in the related cost across years. Hence, when applying equation (6) to a specific year there is a risk that this year is atypical. However, improvements in protection devices during the sample period may have reduced the average cost per accidents between the early and later years in the sample. Hence, there is a risk that we underestimate (overestimate) the marginal costs in earlier (later) years. Albeit we believe that it is preferable to reduce the stochastic variation in accident costs across years to arrive at a more precise estimate of the average cost per accident.

Theory gives us no direct guidance when it comes to model specification. Three natural choices are to estimate the accident probability as:

(i) a linear function

$$P(y=1|X,Q_T)=\Lambda(\delta Q_T+X'\alpha), \tag{7}$$

(ii) a function including a quadratic term

$$P(y=1|X,Q_T)=\Lambda(\delta Q_T+\gamma {Q_T}^2+X'\alpha) \tag{8}$$

(iii) a function of the natural logarithm of train passages

$$P(y=1|X,Q_T)=\Lambda(\eta\ln(Q_T)+X'\alpha) \tag{9}$$

The fact that the distribution of train passages is extremely skewed (see Fig. 1) complicates the analysis. By taking the natural logarithm of train passages the variable becomes more symmetric (Fig. 2). We have tested the fit of the three different alternatives with the data to arrive at preferred model specification. Clearly, the choice of functional form has implications for the estimated marginal cost. The marginal effects in (6)

[4] One of these crossings had two motor vehicle accidents and the other one had one motor vehicle accident and one accident involving vulnerable road users.

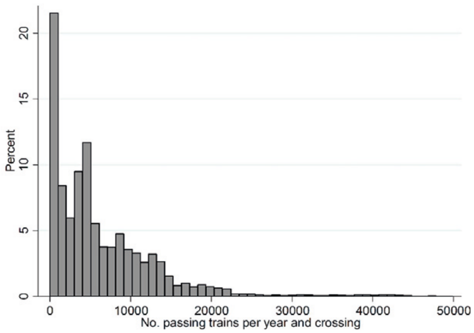

Fig. 1. Traffic volume distribution.

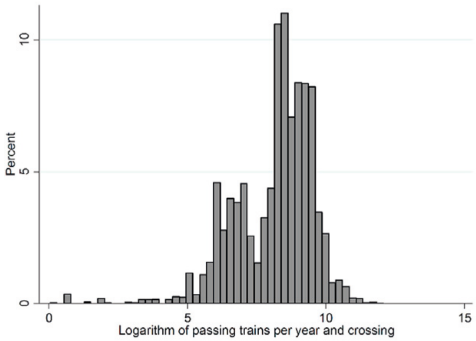

Fig. 2. Logarithm of traffic volume distribution.

corresponding to (7), (8) and (9) are:

$$\partial P/\partial Q_T = \Lambda(W'\beta)(1 - \Lambda(W'\beta))\,\delta, \tag{7a}$$

$$\partial P/\partial Q_T = \Lambda(W'\beta)(1 - \Lambda(W'\beta))\,(\delta + 2\gamma Q_T) \tag{8a}$$

and

$$\partial P/\partial Q_T = \Lambda(W'\beta)(1 - \Lambda(W'\beta))\,\frac{\eta}{Q_T} \tag{9a}$$

respectively where $W' = (Q_T, X)$.

We use equation (6) to obtain an estimated marginal cost per train passing a level crossing using data in 2012 to calculate the marginal effects. The reason for using this year is to provide the most recent year in the data set. This is subsequently aggregated to a weighted average marginal cost per train passage with weights being equal to each crossing's share of the total number of train passages. However, infrastructure charges are usually expressed in terms of vehicle kilometers (or some other measure of distance). For this reason, we convert the weighted average marginal cost per train passage simply by noting that the number of crossings included in the model for motor vehicle accidents in 2012 was 5 406. These crossings were found on 188 different track sections, the total route length of which was 10 369 km. Hence, we divide the weighted average marginal cost by 1.92 (the average distance between crossings) to arrive at an estimate of the external marginal accident cost of motor vehicle accidents per train kilometer. Similarly, the number of crossings included in the model of vulnerable road user accidents in 2012 was 5 765. These crossings were found on 190 different track sections, the total route length of which was 10 415 km. Hence, the weighted average marginal cost is divided by 1.81 (the average distance between crossings) to arrive at an estimate of the external marginal accident cost related to vulnerable road user accidents per train kilometer.

An alternative simpler approach to obtaining an estimate of the marginal external accident cost (cf. equation (6)), is to use the fact that

$$MC = \varepsilon \times AC \tag{10}$$

where ε is the accident elasticity and AC is the average accident cost per train passage. Note that here AC is the average accident cost per train passage whereas C in equation (6) is the average cost per accident. While this formula gives an aggregate estimate of the marginal cost it cannot be used to calculate the marginal cost for a given crossing. Therefore, we instead estimate how the train volume affects the probability of an accident and use equation (6) to estimate the marginal cost for each individual crossing. Equation (10) is used in some sensitivity analyses and to provide an alternative calculation of MC to the weighted average marginal cost presented in the main analysis.

4. Data

The information on accidents, train traffic flows and level crossings was obtained from a database administered by the Swedish Transport Administration. The database ("plk-webb") contains information on existing and closed level crossings with information on, e.g. protection devices, speed limits of the trains, and the type of road that crosses the railway. We have used information pertaining to the years 2008–2012 from this database. For the years 2002–2007 we use information from reported inspections of level crossings in other databases. The dataset used in the analyses presented here is further supplemented with information from 2000 to 2004 from an earlier analysis of accidents between road users and trains at level crossings (Lindberg, 2006).

Information on accidents between 2009 and 2012 has been obtained directly from the aforementioned database. For earlier years the accident records have been retrieved from The Swedish Rail Agency (now The Swedish Transport Agency) in combination with information from the Swedish Transport Administration. Some manual work was required to connect all the accidents to the relevant crossing. For each accident the number of persons killed or injured is recorded. The severity of each injury is classified as either light or severe. Only level crossing accidents leading to personal injuries are included in the analyses and only accidents that involve road users are included; i.e. in the analyses personal injuries among the train crew are not included. Information on suicides and attempted suicides are available in the data on accidents between 2010 and 2012. In our data suicides are only relevant in accidents involving vulnerable road users. We estimate separate vulnerable road user models that include and exclude such accidents. The main reason is that previous recommendations on marginal costs of level crossing accidents in Sweden are based on estimates excluding suicides; see e.g. an earlier edition of the so-called ASEK report (SIKA, 2008).[5] Recent estimates of external marginal costs of road traffic accidents also exclude suicides (Isacsson and Liss, 2016). Hence, comparisons of the results presented here with earlier estimates of the marginal accident cost of level crossing accidents and marginal accident costs on roads should be based on the models estimated on the data set excluding suicides. Nevertheless, we believe that it may be informative to present the results with suicides included in the data set. The main

[5] The ASEK report is the main Swedish document setting out principles, costs, prices and shadow-prices to be used in CBA in the transport sector. The Swedish Transport Administration sets the guidelines and the current version of the report is published on the web site of the Swedish Transport Administration (there is also a summary in English).

reason is that various investments surrounding the railway infrastructure are aimed at preventing suicides.

The information on traffic flows (no. of trains) is collected on a yearly basis. Flows may vary across different parts of each track section but all other information in the analyses pertains to track sections rather than the parts of the track section. Hence, we use a yearly average traffic flow over the whole track section as our measure of railway traffic flow. Furthermore, data on traffic flows for the station areas is imputed.[6] Track sections with a traffic volume of less than one train per year are excluded from the analyses. The number of track sections varies over the years as sections are divided or merged, new sections open and some are closed. The number of different track sections used in the analyses; i.e., sections where we have information on both train traffic flow and existing crossings are 213.[7] The length of the track sections varies from less than one km to nearly 274 km and the number of crossings at each section varies from only one or two (or even zero for some of the years) to almost 300 crossings. In addition, the amount of traffic on each section/crossing varies substantially, as shown in Fig. 1. The distribution is skewed with a mean yearly traffic volume of 6,836, i.e. 19 trains per day, and a median value at 4,619, i.e. 13 trains per day. In Fig. 1 we have excluded the 456 crossings that have more than 50,000 passing trains per year. Fig. 2 displays the corresponding distribution of the logarithm of the number of crossings. This distribution is obviously less skewed.

The data on crossings used in the analysis covers thirteen years (2000–2012). During this period some crossings have been closed, others have been reconstructed with a new type of protection device while some new crossings have also been built.[8] This means that our data set is an unbalanced panel but the variation over time within the same crossing when it comes to traffic flow and protection devices is very small compared to the variation between crossings. The crossings are divided into four categories based on protection device, which obviously also affect accidents rates (Cedersund, 2006): (i) full barriers, (ii) half barriers, (iii) light/sound and (iv) totally unprotected/crossings with crossbucks. Full barriers are barriers that close both the approach side of the crossing and the exit side while half barriers only close the road at the approach side. The category light/sound consists of crossings without barriers but with protection devices in the form of flashing lights and/or sound. The fourth category consists of passive crossings with neither barriers nor lights or sounds. Some of these crossings are equipped with crossbucks or other simple devices while others totally lack protection device. We pool these in a common category. This is motivated by a former study (Cedersund, 2006) on Swedish level crossings showing that crossings with and without crossbucks are equally risky. Hereafter, we call the crossings included in the fourth category unprotected crossings.

Traffic flows of motor vehicles and unprotected road users are important control variables in our models. The larger these flows are, the larger is the probability of an accident during a year. To capture the influence from traffic flow of motor vehicles, information on the type of road that crosses the railway is used as a proxy variable. In a previous Swedish study, Lindberg (2006) compared the results obtained with a model estimated on a sample using this proxy variable and a subsample of his original data including road traffic flow. He found that the same conclusions regarding rail traffic and protection devices could be drawn from both models and that the results regarding the road type reflected

Table 1a
Number of crossings and related accidents (in parentheses) in the sample 2000–2012: motor vehicle accident model.

Year	*Full barriers*	*Half Barriers*	*Light/Sound*	*Unprotected*	*Total*
2000	1016 (3)	926 (0)	561 (0)	4439 (6)	6942 (9)
2001	1004 (0)	920 (1)	529 (1)	4112 (4)	6565 (6)
2002	1067 (0)	946 (0)	633 (2)	4216 (8)	6862 (10)
2003	969 (2)	922 (1)	519 (0)	3433 (2)	5843 (5)
2004	1008 (4)	946 (3)	516 (3)	3468 (4)	5938 (14)
2005	1029 (0)	971 (4)	435 (2)	2950 (6)	5385 (12)
2006	1040 (0)	967 (4)	426 (0)	2774 (5)	5207 (9)
2007	1203 (1)	1042 (1)	652 (2)	4044 (7)	6941 (11)
2008	1216 (1)	1038 (0)	638 (1)	3957 (3)	6849 (5)
2009	1214 (0)	1016 (0)	610 (1)	3523 (1)	6363 (2)
2010	1180 (1)	958 (2)	554 (4)	3132 (3)	5824 (10)
2011	1195 (2)	967 (0)	523 (1)	2899 (1)	5584 (4)
2012	1183 (2)	964 (0)	500 (4)	2759 (4)	5406 (10)

Table 1b
Number of crossings and related accidents including suicides (in parentheses) in the sample 2010–2012: vulnerable road user accident model.

Year	Full barriers	Half barriers	Lights/ sound	Unprotected	Footpaths	Total
2010	1177 (6)	949 (1)	544 (1)	2986 (0)	534 (0)	6190 (8)
2011	1192 (6)	956 (2)	512 (0)	2763 (0)	535 (1)	5958 (9)
2012	1180 (10)	952 (0)	488 (0)	2617 (0)	528 (4)	5765 (14)

the expected road traffic volume. We follow Jonsson (2011) in using three categories for road type: (i) national/regional, (ii) street/other roads, and (iii) private roads.[9] As a proxy variable for the number of vulnerable road users (pedestrians and bicyclists) passing the crossings, we use the number of persons (no age restriction) living within 2 km from the crossing (cf. Isacsson and Liss, 2016). This data has been received from Statistics Sweden. The number of persons living in an area within 2 km from the crossing is 2,188 persons on average (median = 348), and the range is from 0 to 1,08,870 persons.

In Table 1a, the numbers of crossings and accidents are presented for each year included in the model of motor vehicle accidents. The corresponding information included in the model of vulnerable road user accidents is presented in Table 1b. The sum of observations on crossings over all years in the original data pertaining to motor vehicle accidents is 81,309 (years 2000–2012), which implies a yearly average number of crossings of approximately 6,776. Due to missing information on key variables or other problems with the data, we use a total of 79,709 observations on crossings in the model of motor vehicle accidents. The corresponding number of observations used in the model of vulnerable road user accidents is 17,913 (years 2010–2012). Other data problems pertain, for example, to difficulties in matching each individual crossing over the years to other data sources used. Most of the problems pertain to unprotected crossings, which make it look like the number of these crossings is first decreasing and then again is increasing heavily between the years 2006 and 2007. In 2012, our data (from "plk-webb") included 7,178 crossings after all closed crossings are omitted. Another 1,032 crossings are omitted due to no train traffic on those sections (according to data from the Swedish Transport Administration) or because the crossings are located on a yard. Finally, another 210 crossings have to be omitted because of missing data in some of the variables included in our models, resulting in 5,936 crossings in 2012. According to official statistics (Trafikanalys, 2013a) there existed 7,380 level crossings in the Swedish rail network in 2012. The reason why this number differs from our number of crossings is, besides the reasons already mentioned, that our data material is only

[6] The imputation procedure is outlined in Andersson (2006).

[7] Including the Swedish state-owned rail network and the so-called "Inland track" ("Inlandsbanan" in Swedish).

[8] An inspection of the data shows that 90 level crossings have been reconstructed with a new protection device sometime between 2010 and 2012. However, it is difficult from the information in the data to find out when this reconstruction has been made. For these crossings, we have set the year of the reconstruction to 2010.

[9] "Other roads" include *inter alia* roads for pedestrians and bicyclists.

Table 2a
Descriptive Statistics: Distribution of injury severity (including suicides in parentheses) and total number of accidents.

Year	Motor Vehicle Accidents			Vulnerable Road Users Accidents[b]		
	Fatalities	*Severe Injuries*	*Light Injuries*	*Fatalities*	*Severe Injuries*	*Light Injuries*
2000	6	4	0	–	–	–
2001	4	2	2	–	–	–
2002	7	3	6	–	–	–
2003	1	2	3	–	–	–
2004	9	3	2	–	–	–
2005	3	5	10	–	–	–
2006	2	1	9	–	–	–
2007	5	2	5	–	–	–
2008	2	2	1	–	–	–
2009	2	0	0	–	–	–
2010	4	3	4	3 (7)	1 (1)	0 (0)
2011	7	0	0	1 (8)	1 (1)	1 (1)
2012	4	1	9	6 (16)	1 (1)	0 (0)
Total	56	28	51	10 (31)	3 (3)	1 (1)
Number of accidents	107[a]			14 (31)		

[a] In the data there was 107 motor vehicle accidents. However, two of these pertain to the same crossing and is treated as one accident in the empirical analysis.
[b] We only use data on vulnerable road user accidents in 2010–2012 in the analyses for reasons given earlier in the text.

based on information from tracks that are administered by the Swedish Transport Administration (i.e., Swedish state-owned rail network and "Inlandsbanan").

Note also that in the model of motor vehicle accidents no footpath crossings are included. However, we include crossings where the railway is crossed by a road that are for pedestrians only because we consider the possibility that also mopeds and other such motorized vehicles could pass such crossings. In the model of vulnerable road users all types of crossings are included. However, due to the fact that the Swedish Transport Administration earlier did not categorize accidents between vulnerable road users and trains as crossing accidents, we only have information about these accidents for the years 2010–2012. From Tables 1a and 1b we also see that the number of accidents between trains and motor vehicles for the years 2000–2012 is 107 and the number of accidents between trains and vulnerable road users for the years 2010–2012 is 31 (including suicides).

Table 2a presents descriptive statistics on the number of persons being killed and severely or lightly injured in accidents between trains and motor vehicles and vulnerable road users (pedestrians and bicyclists) for each year between 2000 and 2012. The table displays the information excluding and including suicides for the latter type of accident. In 2012, for example, 4 persons were killed and 1 was severely injured and 9 were lightly injured in accidents between trains and motor vehicles. In the same year and excluding suicides, we see that 6 vulnerable road users were killed and 1 was severely injured while no vulnerable road user was lightly injured. The number of vulnerable road users killed in 2012 increases to 16 when we include suicides. At the bottom of the table we see that the total number of motor vehicle accidents in the data set between 2000 and 2012 is 107 (Table 1a contains information on the number of accidents each year). The total number of accidents involving vulnerable road users is 14 when excluding suicides and 31 when including suicides. Note that we only have information for vulnerable road user accidents in 2010, 2011 and 2012.

By combining the totals of fatalities, severe and light injuries in Table 2a with information from the ASEK 6.0 report (Trafikverket, 2016) on the values of saving a statistical life (VSL) and avoiding a statistical severe injury (VSI) and a statistical light injury (VLI), respectively, we can estimate the average costs per accident in the data set (cf. equation (6)). These values cover both material costs in the form of lost income and health care and risk valuation and they are displayed in Table 2b. Here we see that the average cost per accident for motor vehicle accidents is 16.0 million SEK and the corresponding figure for vulnerable road user accidents is 20.9 million SEK when excluding suicides. The latter figure increases to 28.2 million SEK when including suicides in the calculation.

Table 2b
Descriptive Statistics: VSL[a], VSI[b] and VLI[c] (Millions SEK) and average cost per accident (C) - Millions SEK (including suicides in parentheses).

	Motor Vehicle Accidents			Vulnerable Road Users Accidents		
	VSL[a]	*VSI*[b]	*VLI*[c]	*VSL*[a]	*VSI*[b]	*VLI*[c]
Value[d]	27.7	5.1	0.3	27.7	5.1	0.3
C	16.0			20.9 (28.2)		

Notes: SEK 1 ≈ EUR 0.1.
[a] VSL is short for the value of a statistical life.
[b] VSI is the value of a statistical severe injury.
[c] VLI is short for the value of a statistical light injury.
[d] Price level in 2017.

Table 3 presents the total number of train passages in level crossings for each year by type of accident (motor vehicle accidents or vulnerable road user accidents) and type of protection device (full barriers, half barriers, light/sound, unprotected and footpaths). We see for example that in 2012 some 15 million trains passed crossings where the protection device was full barriers. We also see that there is an increase between 2000 and 2012 in the number of trains passing crossings with full barriers and that the number of trains passing unprotected crossings decreases between the same years. This is partly an effect of changes in the number of crossings with different protection devices observed in the data discussed above (cf. Table 1a). Note also that the change over time in total number of train passages depend on the total number of crossings included in the data set (cf. Table 1a).

Table 4a presents the total number of train passages summed over the different types of crossing in Table 3, the corresponding total accident cost and average accident cost per train passage pertaining to motor vehicle accidents for each year 2000–2012. Here we see for example that the total accident cost in 2012 was 118.60 million SEK and that the corresponding average cost per train passage was 3.00 SEK. There is a dip in the total number of train passages between 2009 and 2010. This was explained earlier in this section (cf. Table 1a). Table 4b presents the corresponding information pertaining to vulnerable road user accidents. Here we see, for example, that the total accident cost in 2012, excluding suicides, was 171.30 million SEK and that the corresponding average cost per train passage was 3.88 SEK. The corresponding figures when including suicides are 448.30 million SEK and 10.17 SEK.

5. Results

5.1. Model specification and results

It seems likely that the flow of traffic increases the probability of an accident by increasing the number of occasions when a train can collide with a road vehicle or a vulnerable road user (conditional on crossing characteristics). In other words, exposure will increase with the traffic volume of both trains and road vehicles or pedestrians. The speed of both the trains and the road vehicles also influences the probability of an accident. At the same time, a crossing with more frequent train traffic will induce a more precautional behaviour from the road users hence reducing the probability of an accident. This behavioural effect among road users could in some traffic situations override the effect from more collision occasions. In that case the accident probability would fall with the number of passing trains and the marginal cost

Table 3
Descriptive Statistics: Total number of train passages (millions) by type of crossing and year in the sample.

Year	Full barriers		Half barriers		Light/sound		Unprotected		Footpaths	
	MVA[a]	VRUA[b]	MVA[a]	VRUA[b]	MVA[a]	VRUA[b]	MVA[a]	VRUA[b]	MVA[a]	VRUA[b]
2000	11.03	–	8.38	–	3.04	–	19.12	–	–	–
2001	11.74	–	8.86	–	2.90	–	18.24	–	–	–
2002	12.61	–	9.11	–	3.71	–	18.33	–	–	–
2003	11.53	–	9.57	–	3.75	–	16.69	–	–	–
2004	11.98	–	9.81	–	3.60	–	17.40	–	–	–
2005	11.83	–	10.16	–	2.37	–	15.82	–	–	–
2006	11.97	–	10.22	–	2.33	–	15.64	–	–	–
2007	13.85	–	10.61	–	2.93	–	16.53	–	–	–
2008	14.64	–	10.65	–	2.97	–	16.46	–	–	–
2009	15.13	–	10.54	–	2.99	–	16.39	–	–	–
2010	14.36	14.34	9.48	9.42	2.54	2.54	12.32	12.21	–	4.45
2011	14.35	14.32	9.45	9.39	2.57	2.55	11.90	11.79	–	4.55
2012	15.04	15.02	9.89	9.81-	2.65	2.63	11.92	11.78	–	4.85

[a] MVA is short for motor vehicle accidents.
[b] VRUA is short for vulnerable road user accidents.

Table 4a
Total number of train passages in the data set, total accident cost (TC) and average accident cost (AC) per train passage for the years 2000–2012: motor vehicle accidents.

Year	Total Number of Train Passages (Millions)	TC (Millions SEK)	AC (SEK)
2000	41.57	186.60	4.49
2001	41.74	121.60	2.91
2002	43.76	211.00	4.82
2003	41.56	38.80	0.93
2004	42.79	265.20	6.20
2005	40.17	111.60	2.78
2006	40.16	63.20	1.57
2007	43.92	150.20	3.42
2008	44.73	65.90	1.47
2009	45.04	55.40	1.23
2010	38.70	127.30	3.29
2011	38.27	193.90	5.07
2012	39.50	118.60	3.00
2000–2012	541.90	1709.30	3.15

Note: SEK 1 ≈ EUR 0.1.

Table 4b
Total number of trains passages in the data set, total cost (TC) and average cost (AC) per train passage for the years 2000–2012: vulnernable road user accidents (costs including suicides within parentheses).

Year	Total Number of Train Passages (Millions)	TC (Millions SEK)	AC (SEK)
2010	42.96	88.20 (199.00)	2.05 (4.63)
2011	42.61	33.10 (227.00)	0.78 (5.33)
2012	44.10	171.30 (448.30)	3.88 (10.17)
2010–2012	129.67	292.60 (874.30)	2.26 (6.74)

Note: SEK 1 ≈ EUR 0.1.

would be negative. Thus, it seems relevant to consider the functional form of the empirical model relating accidents to traffic flows.[10] For accidents involving motor vehicles we tested the functional forms outlined in equations (7)–(9).

Table 5 shows the results from models estimating the probability of level crossing accidents involving motor vehicles. As can be seen in Table 5, the logarithm of train passages (*ln(Q)*) significantly increases the accident probability (specification 9). Since the probability of an accident is very low in the sample, the parameter indicates that the average accident elasticity is close to 0.51.[11] The road type variables are significant and with the expected signs where crossings with streets/other roads and private roads have a significantly lower accident probability than the reference category national/regional roads where the flow of cars are relatively large. Crossings with full and half barriers have a significantly lower accident probability than the reference category crossings with lights/sound while the unprotected crossings do not differ from the reference category. The table also shows the average marginal cost per train passage calculated for each crossing using equation 7', 8' or 9' and then taking a weighted mean with weights being equal to each crossing's share of the total number of train passages. We can see that the marginal cost is similar for specification 8 and 9 while the linear model in specification 7 gives a substantially lower average marginal cost. In all three specifications the traffic flow of trains is significant and positive, implying that more passing trains increase the accident probability. The calculations in the rest of the paper will be based on the logarithmic model, i.e. specification 9.

In Table 6, we present the results from the model of accidents involving vulnerable road users.[12] Remember that in this model, only observations from the years 2010–2012 are included, and therefore the number of observations is much smaller than in the motor vehicle accidents model. Here we focus on the logarithmic specification of the model. However, and as noted earlier, for vulnerable road users it is important to consider potential differences between the model estimated on the sample with or without suicides included. The logarithm of train passages increases the accident probability also in this model. The probability of an accident is very low also in this sample hence the parameter indicates that the average accident elasticity is close to 0.37 in the model excluding suicides and close to 0.88 when suicides are

[10] More precautional behaviour is not without cost (Steimetz, 2008). This risk-reducing behaviour in the form of speed reduction or possible anxiety that the road user feels when passing a crossing that is perceived as unsafe should be included in a full measure of the accident cost. Unfortunately, it is impossible or at least very hard to observe this risk-reducing behaviour and our measure of the accident externality from train traffic therefore only includes the estimated effect on the accident probability and not the increase in accident avoidance costs for the road users. A level crossing accident may also lead to costs in the form of time delays for both train users and road users. This cost is not included in our estimates.

[11] From equations 9 and 9a we see that the accident elasticity is equal to $\frac{\partial P}{\partial Q_T}\frac{Q_T}{P} = (1 - \Lambda(W'\beta))\,\eta$.

[12] In 106 observations, the number of persons living within 2 km from the crossing was zero. Because we use the logarithm of this variable in the model, we chose to replace these values with the value 1 to not loose these observations. A comparison between a model with and without these observations show that the values of the coefficients were exactly the same.

Table 5
Regression results and implied marginal costs, motor vehicle accidents.

	Specification (7)	Specification (8)	Specification (9)
Constant	−5.26*** (0.26)	−5.68*** (0.31)	−9.13*** (0.71)
Q/1000	0.02*** (0.004)	0.15*** (0.04)	–
Q^2/10 000 000	–	−0.03† (0.02)	–
ln(Q)	–	–	0.51*** (0.08)
National/regional roads	Reference	Reference	Reference
Street/other road	−0.79** (0.27)	−0.97*** (0.28)	−0.97*** (0.28)
Private road	−2.78*** (0.47)	−2.95*** (0.47)	−2.93*** (0.47)
Lights/sound	Reference	Reference	Reference
Full barrier	−1.35*** (0.34)	−1.77*** (0.36)	−1.83*** (0.36)
Half barrier	−1.20*** (0.32)	−1.68*** (0.34)	−1.65*** (0.32)
Unprotected	−0.09 (0.29)	−0.07 (0.28)	−0.08 (0.27)
Average marginal cost per train passage (SEK) in 2012	0.52	1.42	1.51
Average marginal cost per train km (SEK) in 2012	0.27	0.74	0.79
AIC	1561.08	1539.87	1532.52
BIC	1626.08	1614.16	1597.52
N	79 709	79 709	79 709

Notes. Standard errors within parentheses are corrected for clustering on crossing. †p = .051.
*p < .05, **p < .01, ***p < .001. SEK 1 ≈ EUR 0.1.

Table 6
Regression results from the logarithmic model and implied marginal costs, vulnerable road user accidents.

	Model excluding suicides	Model including suicides
Constant	−17.51*** (2.08)	−19.45*** (1.70)
Ln(Q)	0.37 (0.24)	0.88*** (0.23)
Ln(Number of persons within 2 km)	0.91*** (0.19)	0.68*** (0.13)
Average marginal cost per train passage (SEK) in 2012	0.79	5.02
Average marginal cost per train km (SEK) in 2012	0.44	2.77
AIC	176.88	353.82
BIC	200.26	377.20
N	17 913	17 913

Note. Standard errors within parentheses are corrected for clustering on crossing. *p < .05, **p < .01, ***p < .001. SEK 1 ≈ EUR 0.1.

included. The p-value of the estimated parameter in the model excluding suicides is, however, slightly above 10 percent indicating that the number of train passage is not significantly different from zero at conventional levels of significance. Hence, the implied weighted average marginal cost per train passage and the corresponding marginal cost per train kilometer must be interpreted cautiously. With this remark in mind we note that the average marginal cost in 2012 per train passage is 0.79 SEK and 0.44 SEK per train kilometer when suicides are excluded. The model including suicides suggests that the corresponding figures are 5.02 SEK per train passage and 2.77 SEK per train kilometer.

5.2. Marginal cost heterogeneity

From equation (9a) it is clear that the marginal cost will vary between different crossings depending on crossing characteristics. This heterogeneity in the estimated marginal cost is displayed in Table 7. The table shows weighted average marginal cost estimates per passage for each combination of road type and protection device where crossings with many passages have a higher weight than crossings with few passages. Because the marginal effect decreases with the number of passages, the differences between the crossings increases when weighting by the number of passages compared to taking an unweighted average across the crossings. The differences between crossings reflect both differences in protection device, road type, and number of train passages.

5.3. Sensitivity tests

We have conducted a number of sensitivity tests of the results pertaining to specification 9 of the motor vehicle accident model.

First, in the main analysis of the model of motor vehicle accidents we used road type as a proxy for the flow of motor vehicles. An alternative to this is to use the logarithm of the number of persons within 2 km of each crossing; i.e. the same control variable for traffic flow as in the model of accidents involving vulnerable road users. Using this variable instead of road type with imputed values for the years 2000–2009 gives significant results for the number of persons within 2 km and an accident elasticity similar to the one in the model specification with road types. Regression results are provided in Appendix 1, Table A1.

Secondly, using road type as a proxy for motor vehicle flows fails to account for potential trends in motor vehicle flows. Hence, there is a risk that the effect of motor vehicle flows will wrongfully be picked up by the number of train passages. For this reason, we estimated a model including a full set of yearly dummy variables. The estimated accident elasticity was more or less the same, however, as in the model reported in Table 5 (specification 9), see Table A1 in Appendix 1.

Thirdly, the number of accidents is rather small in a given year and varies substantially across the years in the sample. To illustrate this, we calculated the marginal accident cost per train passage using equation (10) for each year 2000–2012 and present the results in Table A2 for motor vehicle accidents and Table A3 for accidents involving vulnerable road users in Appendix 1. Since the probability of an accident is ‘small’, the accident elasticity is approximately equal to the parameter related to the logarithm of train passages (specification 9 in Table 5). By comparing the results obtained with equation (10) applied to specification 9 in 2012 to the properly calculated weighted average marginal cost in Table 5, we also provide an assessment of the accuracy of using the simple formula in equation (10).

Tables A2 and A3 illustrate the large variation in marginal costs per train passage across different years. Here we see that marginal costs of motor vehicle accidents vary from 0.47 SEK to 3.16 SEK. The corresponding figures of vulnerable road user accidents (excluding suicides) are 0.69 SEK and 3.42 SEK. This is a result of the relatively large variation across years in average accident cost and it implies that it may be advisable to use an average accident cost over several years to derive an expected average and marginal accident cost suitable for pricing.

Train speed probably also influences the accident probability and one way of capturing train speed is to distinguish between freight trains and passenger trains where freight trains in general are slower than passenger trains. The problem is however that we cannot distinguish between accidents involving passenger trains and accidents involving freight trains. It is, however, possible to separate the number of train passages at each level crossing in terms of freight and passenger trains. This may seem to suggest a possibility to estimate separate accident elasticities for freight and passenger trains. Nevertheless, the restriction on the information of the dependent variable may imply that it is advisable to use the corresponding restriction on the independent

Table 7
Marginal cost per train passage for different combinations of road type and protection device – based on weighted average traffic and motor vehicle accidents, year 2012 (SEK).

	Full barrier	Half barrier	Light/sound	Unprotected
National/regional	1.12	1.60	17.82	–
Street/other road	0.47	0.62	4.26	3.89
Private road	0.06	0.07	0.43	0.63

Notes. The marginal costs are derived from specification 9 of the model. SEK 1 ≈ EUR 0.1.

variable; i.e. to use the sum of freight and passenger trains passages. In Appendix 2 the results from simulations are presented and they show that if the accidents are generated by the flow of passenger trains and freight trains separately, estimating a model where only the traffic flow is separated but not the accidents will result in underestimations of the elasticities for both freight trains and passenger trains. Our estimation models seem to provide unbiased estimates of the true parameters related to the logarithm of the passages when the generating processes of accidents involving freight and passenger trains are the same. When the data generating processes of accidents involving freight and passenger trains differ our estimation models seem to produce an unbiased estimate of the average of the true parameters. See Appendix 2 for details.

6. Discussion

In this paper, we have estimated accident probability models for level crossing accidents both for motor vehicles and for vulnerable road users (pedestrians and bicyclists) and based on these models we estimated marginal accident costs. The results show that the probability of an accident increases with the train traffic volume and that the marginal costs differ substantially between different road types and between different protection devices. The probability of an accident also increases as the number of persons living nearby a crossing increases.

The accident charge per km in the present study was estimated to SEK 0.79 for accidents between trains and motor vehicles and SEK 0.44 for accidents involving vulnerable road users (SEK 2.77 if we include suicides). This can be compared to the results in an earlier study using accident records for 2000–2008 (Jonsson, 2011). In the earlier study, the weighted average marginal cost per train passage was estimated to a value of SEK 1.13 in 2008, compared to SEK 1.51 for motor vehicle accidents in 2012 in the present study. Besides including vulnerable road users in the present paper, we have enlarged the data set, which now also includes the years 2009–2012. We also base the estimation on other data regarding traffic volume, which now includes station areas. The values used for the different injury severity levels are also updated according to the official Swedish values, which can explain some of the difference in average marginal cost between the two studies.[13]

This estimated accident cost is external to the train operator as it consists of the costs of the injuries to the road user and material damage to the road vehicle. The cost that falls on the train operator in the form of delays or material damage to the train is not included in our estimates. This motivates using our estimated marginal external accident cost for charging the train operators. However, we cannot calculate how full internalization of the accident cost would influence the number of accidents. To do that we need to know how the train operators would react to increased track charges and to what extent the increased track charge would result in a lower train volume. No estimates of such a train volume elasticity exist for the Swedish rail network. Considering the importance of this elasticity in this context, this seems like a highly relevant issue for future research.

We consider it possible to add the average marginal cost of motor vehicle accidents and the average marginal cost of vulnerable road users to arrive at a total average marginal accident cost. The crossings in the two models are indeed overlapping, but the accidents and the accident costs are unique in each model. However, further work on the models for vulnerable road users seems necessary. A main reason is that the average marginal cost of vulnerable road user accidents (excluding suicides) is based on an accident elasticity that is only close to being significantly different from zero at the 10 percent level. Hence it is advisable to interpret the related marginal costs carefully. Furthermore, it is unclear how suicides among the unprotected road users should be treated in the context of marginal costs. We have only noted that some previous Swedish studies have excluded them in the calculation.

Our estimated external accident cost at 0.79 SEK per km for accidents involving motor vehicles and 0.44 for accidents involving vulnerable road users can be compared to the track charges paid by passenger trains and freight trains. These vary by geography, time and train characteristics but the average track charge for passenger trains was 9 SEK/km and for freight trains 15 SEK/km in 2018.[14] This means that our estimated external accident costs together correspond to around 10 percent of the current track charge.

Our estimated external marginal costs may also be compared to corresponding estimates of road traffic. Isacsson and Liss (2016) present a recent update of estimates of the external marginal costs pertaining to light and heavy vehicles on the national network of roads in Sweden (these roads are mostly located outside urban areas). Their results indicate that the external marginal cost per vehicle kilometer is close to zero for light vehicles and 0.28 SEK per vehicle kilometer for heavy vehicles (converted to the price level in 2017). These relatively low values may seem somewhat surprising since train traffic is usually regarded as safer than road traffic. However, it should be noted that a large fraction of the total accident costs is internal to light vehicles on this road network. This is also true of heavy vehicles although to a lesser extent than light vehicles. Clearly, the external marginal costs of road traffic are larger in urban areas where the flows of vulnerable road users (pedestrians and bicyclists for example) are larger than outside urban areas. In the ASEK report 6.0 (Trafikverket, 2016), for example, the corresponding external marginal costs in Swedish urban areas are 0.26 SEK per km for light vehicles and 0.63 SEK per km for heavy vehicles (converted to the price level in 2017).

We have also presented three different specifications of the probability model of motor vehicle accidents. Two of these provide similar estimates of the average marginal accident cost with one of these being the preferred specification. This does not imply, however, that the estimated marginal cost for specific crossings need to be similar in the two specifications. The reason is that they deal with the non-linearity of the relationship between accidents and traffic flow in somewhat different ways and the marginal cost of a specific crossing depends *inter alia* on the traffic volume. More specifically, the quadratic specification implies that for large enough values of the train traffic flow, the marginal cost may have the ‘wrong’ sign whereas this is not the case with the preferred logarithmic specification. Hence in some instances it may be important to consider how the selected model behaves for different values of traffic flow. This is obviously related to the intended use of the model.

Although we have conducted a number of sensitivity analyses we note that the estimated marginal costs may be sensitive to a number of

[13] Since this article was written the Swedish values for fatalities and injuries in the transport sector has been further updated and almost doubled. This gives that also our estimated marginal costs increase substantially when using these updated values. As the results presented in this article is part of a research project where the earlier values were used for different marginal cost estimations we have chosen not to change our calculations in the article to be able to compare our results to the other marginal cost estimations in the project.

[14] The calculated average track charge is based on (Trafikanalys, 2019), Tables 2.2 and 2.3 (in Swedish).

other issues; e.g. missing data, the exclusion of accidents resulting in no injuries or fatalities, and the use of proxy variables for the flow of motor vehicles and vulnerable road users. There may also be additional cost elements that were not considered here; e.g. the cost of precautional behaviour and non-internalised costs of disturbances in rail traffic. These issues are left for future research.

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A1. APPENDIX. Sensitivity tests

Table A1
Regression results and implied marginal costs for motor vehicle accidents. Model that uses the number of persons within 2 km as proxy for road traffic flow and a model including yearly dummy variables.

	Sensitivity test 1: Number of persons within 2 km as proxy for road traffic flow	Sensitivity test 2: Including full set of yearly dummy variables
Constant	−10.17*** (0.78)	−8.76*** (0.83)
Ln(Q)	0.45*** (0.09)	0.50*** (0.08)
Ln(Number of persons within 2 km)	0.12* (0.06)	–
National/regional roads	–	Reference
Street/other road	–	−0.98*** (0.28)
Private road	–	−2.95*** (0.47)
Lights/sound	Reference	Reference
Full barrier	−1.75*** (0.37)	−1.83*** (0.36)
Half barrier	−1.18*** (0.33)	−1.66*** (0.32)
Unprotected	−0.87** (0.27)	−0.08 (0.27)
Year 2000	–	−0.29 (0.46)
Year 2001	–	−0.66 (0.52)
Year 2002	–	−0.19 (0.45)
Year 2003	–	−0.78 (0.55)
Year 2004	–	0.22 (0.42)
Year 2005	–	0.17 (0.43)
Year 2006	–	−0.10 (0.46)
Year 2007	–	−0.07 (0.44)
Year 2008	–	−1.10 (0.59)
Year 2009	–	−1.77* (0.77)
Year 2010	–	−0.03 (0.45)
Year 2011	–	−0.91 (0.59)
Year 2012	–	Reference
Average marginal cost per train passage (SEK) in 2012	1.28	2.01
Average marginal cost per train km (SEK) in 2012	0.67	1.05
AIC	1400.17	1533.71
BIC	1455.13	1710.15
N	70 232	79 709

Notes. Standard errors within parentheses are corrected for clustering on crossing. *p < .05, **p < .01, ***p < .001. SEK 1 ≈ EUR 0.1.

Table A2
Total number of train passages in the data set, total accident cost (TC), average accident cost (AC) and marginal cost (MC) per train passage for the years 2000–2012: motor vehicle accidents

Year	Total Number of Train Passages (Millions)	TC (Millions SEK)	AC (SEK)	MC (SEK)
2000	41.57	186.60	4.49	2.29
2001	41.74	121.60	2.91	1.48
2002	43.76	211.00	4.82	2.46
2003	41.56	38.80	0.93	0.47
2004	42.79	265.20	6.20	3.16
2005	40.17	111.60	2.78	1.42
2006	40.16	63.20	1.57	0.80
2007	43.92	150.20	3.42	1.74
2008	44.73	65.90	1.47	0.75
2009	45.04	55.40	1.23	0.63
2010	38.70	127.30	3.29	1.68
2011	38.27	193.90	5.07	2.59
2012	39.50	118.60	3.00	1.53
2000–2012	541.90	1709.30	3.15	1.61

Notes: SEK 1 ≈ EUR 0.1. Marginal costs obtained with equation (10).

Table A3
Total number of trains passages in the data set, total cost (TC), average cost (AC) and marginal cost (MC) per train passage for the years 2000–2012: vulnerable road user accidents (costs including suicides within parentheses)

Year	Total Number of Train Passages (Millions)	TC (Millions SEK)	AC (SEK)	MC (SEK)
2010	42.96	88.20 (199.00)	2.06 (4.64)	1.81 (4.08)
2011	42.61	33.10 (227.00)	0.78 (5.34)	0.69 (4.70)
2012	44.10	171.30 (448.30)	3.89 (10.18)	3.42 (8.96)
2010–2012	129.67	292.60 (874.30)	2.26 (6.76)	1.99 (5.95)

Note: SEK 1 ≈ EUR 0.1. Marginal costs obtained with equation (10).

A2. APPENDIX. Simulated data

It is not possible to separate the dependent variable of the empirical models into accidents involving freight trains from those involving passenger trains. It is, however, possible to separate the number of train passages at each level crossing in terms of freight and passenger trains. This may seem to suggest a possibility to estimate separate accident elasticities for freight and passenger trains. Nevertheless, the restriction on the information of the dependent variable may imply that it is advisable to use the corresponding restriction on the independent variable; i.e. to use the sum of freight and passenger trains passages. But it is relevant to consider how the estimated model relates to the underlying data generating process.

Below we use simulated data to investigate this issue. More specifically we investigate:

(i) how our chosen estimation models relate to the true parameters of the data generating processes
(ii) how a model where we separate the total number of train passages into freight and passenger trains relates to the true parameters of the data generating processes.

We conduct this investigation under two different assumptions regarding the data generating processes (dgp:s): one where the accident elasticities of the dgp:s of freight and passenger train accidents are the same and one where they are not the same. Each of the two simulation exercises involve 100 samples ($R = 100$) with 1,00,000 observations ($N_r = 100\,000$; r = 1, 2, …, R) in each sample. This simulation exercise is outlined in more detail below.

In the first step, we generate independent pairwise (x, z) draws from a negative binomial distribution (we add 1 to x and z to avoid missing values when subsequently taking the logarithm of these numbers) with the parameter for the probability of success set to 0.01 and the parameter for the number of successes set to 8. These variables (x, z) correspond to the number of freight and passenger trains, respectively, in each level crossing. In the second step, the logarithms of these draws are produced and a correlation between the logarithm of x and the logarithm of z are introduced to reflect approximately the same correlation between the logarithm of freight trains and the logarithm of passenger trains observed in the real data used in the present paper. In the third step related "probabilities" of an accident (P_x and P_z) are produced according to the logistic distribution; i.e.:

$$P_x = \exp(\alpha_0 + \alpha_1 logx)/(1 + \exp(\alpha_0 + \alpha_1 logx)) \quad \text{(dgp1)}$$

and

$$P_z = \exp(\beta_0 + \beta_1 logz)/(1 + \exp(\beta_0 + \beta_1 logz)) \quad \text{(dgp2)}$$

In the fourth step these "probabilities" are converted to two variables Y_x and Y_z that each takes the values 0 (no accident) or 1 (accident) using independent draws from a Bernouilly distribution with parameters P_x and P_z, respectively. The two variables Y_x and Y_z would correspond to separate observations on accidents for freight and passenger trains *if the information had been available in the real data set*. In the fifth step, we take the sum of Y_x and Y_z to simulate the dependent variable *actually available in the real data set* used for the empirical analyses of the present paper. If the sum is greater than one for an observation we set the value to one in accordance with the treatment of multiple accidents in a level crossing in the empirical analyses of the paper. In the following we denote this variable Y.

To sum up, with these simulated data we can now estimate, for each of the simulated samples, the parameters in the following logit models:

$$Prob(Y_x = 1) = \exp(\gamma_0 + \gamma_1 logx)/(1 + \exp(\gamma_0 + \gamma_1 logx)) \quad \text{(E1)}$$

$$Prob(Y_z = 1) = \exp(\delta_0 + \delta_1 logz)/(1 + \exp(\delta_0 + \delta_1 logz)) \quad \text{(E2)}$$

$$Prob(Y = 1) = \exp(\theta_0 + \theta_1 \log(x + z))/(1 + \exp(\theta_0 + \theta_1 \log(x + z))) \quad \text{(E3)}$$

$$Prob(Y = 1) = \exp(\rho_0 + \rho_1 logx + \rho_2 logz)/(1 + \exp(\rho_0 + \rho_1 logx + \rho_2 logz)) \quad \text{(E4)}$$

Estimation equations E1 and E2 are used to verify that estimation with the simulated data replicates the parameters of dgp1 and dgp2, respectively. More specifically, we expect to find that: $\gamma_0 = \alpha_0$; $\gamma_1 = \alpha_1$; $\delta_0 = \beta_0$; $\delta_1 = \beta_1$.

Equation (E3) corresponds to the estimation equations used in the main analyses of the present paper. Here we are interested in the relationship between θ_1 on the one hand and α_1 and β_1 on the other hand. If $\alpha_1 = \beta_1$ in the two dgp:s, we expect that $\theta_1 = \alpha_1 = \beta_1$.

Equation (E4) is used to investigate the relationship between: (i) ρ_1 and α_1; and (ii) ρ_2 and β_1. In other words, here we investigate whether it is possible to obtain separate risk elasticities for freight and passenger trains with the data available for the main analyses of the present paper.

Tables A4a and A4b summarize the estimation results of E1-E4 for two alternative data generating processes. The main conclusions of these tables are the following:

(i) When the data generating processes of accidents involving freight and passenger trains (cf. dgp1 and dgp2) are the same:
  (a) Our estimation models seem to provide unbiased estimates of the true parameters related to the logarithm of the passages.
  (b) A model where the total number of passages are separated into freight and passenger trains seem to produce downward biased estimates of the true parameters related to the logarithm of the passages.

(ii) When the data generating processes of accidents involving freight and passenger trains (cf. dgp1 and dgp2) differ:
  (a) Our estimation models seem to produce an unbiased estimate of the average of the true parameters (Test 3 in Table A4b).
  (b) A model where the total number of passages are separated into freight and passenger trains produces downward biased estimates of the true parameters related to the logarithm of the passages.

Table A4a
Results of estimation equation (E1)-E4: Averages of estimated parameters and related standard deviations within parentheses – Same parameters in the two dgp:s

Parameters of dgp1 and dgp2: $\alpha_0 = \beta_0 = -8$ and $\alpha_1 = \beta_1 = 0.5$

	E1	E2	E3	E4
Intercept	−8.001 (0.693)	−7.967 (0.804)	−7.699 (0.681)	−7.312 (0.603)
logx	0.501 (0.105)	–	–	0.232 (0.058)
logz	–	0.495 (0.115)	–	0.270 (0.081)
$\log(x + z)$	–	–	0.517 (0.092)	–
Test 1: slope $= \alpha_1$	0.005	–	0.189	−4.615
Test 2: slope $= \beta_1$	–	−0.042	0.189	−2.857

Notes: The number of replicated samples is 100 and the sample size of each replicated sample is 100 000. *Test* is a standard *t*-test of the equality between the estimated slope coefficients in each model and the related true values of the two dgp:s. It is based on the sample averages and standard deviations. In E4 Test 1 refers to a test of $\rho_1 = \alpha_1$ and Test 2 refers to a test of $\rho_2 = \beta_1$.

Table A4b
Results of estimation equation (E1)-E4: Averages of estimated parameters and related standard deviations within parentheses– Different parameters in the two dgp:s

Parameters of dgp1 and dgp2: $\alpha_0 = -10$; $\beta_0 = -8$ and $\alpha_1 = 0.9$; $\beta_1 = 0.5$

	E1	E2	E3	E4
Intercept	−10.026 (0.505)	−7.976 (0.695)	−9.103 (0.681)	−8.494 (0.540)
logx	0.903 (0.075)	–	–	0.563 (0.059)
logz	–	0.496 (0.099)	–	0.175 (0.064)
$\log(x + z)$	–	–	0.758 (0.081)	–
Test 1: slope $= \alpha_1$	0.046	–	−1.764	−5.704
Test 2: slope $= \beta_1$	–	−0.039	3.188	−5.110
Test 3: slope $= (\alpha_1 + \beta_1)/2$	–	–	0.712	–

Notes: The number of replicated samples is 100 and the sample size of each replicated sample is 100 000. *Test* is a standard *t*-test of the equality between the estimated slope coefficients in each model and the related true values of the two dgp:s. It is based on the sample averages and standard deviations. In E4 Test 1 refers to a test of $\rho_1 = \alpha_1$ and Test 2 refers to a test of $\rho_2 = \beta_1$.

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Paper III

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The unexpected "yes": Explanatory factors behind the positive attitudes to congestion charges in Stockholm

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ABSTRACT

Several authors have argued that acceptability for road pricing is likely to increase with familiarity. The experiences in Stockholm, where a trial period with congestion charges changed the public opinion from negative to positive, support this hypothesis. Analysing acceptability and attitudes in Stockholm allows us to study a situation where the population *is* in fact familiar with congestion charges, and explore what the decisive factors for acceptability are in such a situation. By analysing a survey collected after the referendum and the subsequent reintroduction of the charges, we analyse the prerequisites to achieve acceptability given that the public is familiar with congestion charges.

As expected, low car dependence and good transit supply are associated with high acceptability. But the two most important factors turn out to be beliefs about the charges' effectiveness, and general environmental attitudes. The importance of beliefs and perceptions of the effects of the charges underscores the importance of both careful system design and careful evaluation and results communication. The strong connection between environmental concerns and positive attitudes to congestion charges underscores the importance of considering and "marketing" the charges' environmental effects. In Stockholm, the politicians' decision to "re-label" the congestion charges to "environmental charges" and emphasising their positive effects on air quality may very well have had a positive impact on acceptability.

1. Introduction

Congestion pricing has been long advocated by transport economists and traffic planners as an efficient means to reduce road congestion. Despite growing problems with urban congestion and urban air quality, and despite a consensus that investments in roads or public transit will not be sufficient to tackle these problems, very few cities have introduced congestion pricing. The main obstacle seems to be a lack of public acceptability, making politicians reluctant to try the measure.

Several authors have argued that acceptability of road pricing is likely to increase with familiarity (e.g. Jones, 2003, p. 37). This has made several proponents of congestion charging advocate that charges be introduced even against public opposition, perhaps in trial form, since the benefits would be so large, and the public opposition would falter once the benefits become obvious. This was also what happened in both Stockholm and London, where congestion charges were introduced in 2006 and 2004, respectively. Congestion charges were introduced in Stockholm as a trial in 2006, in spite of significant public resistance, followed by a referendum where a majority supported keeping the charges. The charges were hence reintroduced in 2007, and support for them has since then grown even stronger.

Analysing acceptability and attitudes in Stockholm allows us to study a situation where the population *is* in fact familiar with congestion charges—the concept, its effects on traffic and environment and its impact on their daily life. It allows us to explore if the plan to "introduce first, get acceptability later" is likely to succeed in other cities. Put differently: what are the prerequisites to achieve acceptability *given* that the public *is* familiar with congestion charges. This is the purpose of the present paper.

The "familiarity breeds acceptability" hypothesis is supported by empirical experience from other cities as well—for Norwegian experience, see Tretvik (2003), for London, see Schade and Baum (2007), for Stockholm, see Winslott-Hiselius et al. (2009) and Brundell-Freij and Jonsson (2009). There are probably several reasons for acceptability to increase with familiarity with a real system. One oft-quoted reason in Stockholm was that the positive effects on road congestion and urban environment were much larger than most people expected. Several authors have noted that a main reason for the resistance against congestion charges is

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the belief that they will not "work". In the words of Jones (2003): "The public not only dislikes charges, it thinks it will not be effective". A second, also oft-quoted reason is that the public fear that travel costs will increase more and/or their travel patterns will have to change more than is actually the case. Once the charges are in place, many people may realise that the charges in fact do not affect them as much as they had thought. Stockholm evidence of this phenomenon is reported in Henriksson (2009). A third reason is the psychological effect known as cognitive dissonance, a phenomenon that can be simply summarised as "accept the unavoidable". In other words, once the charges are in place, it is less worthwhile to spend energy on opposing them. A fourth reason may be decreased reluctance towards pricing a previously unpriced good. There is evidence that "people in many cases do not like prices as an allocation mechanism" (Frey, 2003, p. 65; see also Jones, 2003). But once familiar with the thought that road space is in principle a scarce good that can be priced – much like parking space or telecommunication capacity – this reluctance may tend to decrease.

The Stockholm case is interesting for many reasons. Obviously, the opportunity to gauge the effects of congestion charges on traffic, congestion levels and travel behaviour has attracted great interest (see Eliasson et al, 2009; Eliasson, 2009a,b). But perhaps even more interesting is the fact that the congestion charges survived a very complicated political and legal process, and a dedicated referendum that had initially been forced through by the opponents of the charges. In many ways, the most interesting from the perspective of other cities is the story of how and why the Stockholm charges went from "the most expensive way ever devised to commit political suicide[1]" to something termed by initially hostile media as a "success story" (newspaper *Dagens Nyheter*, June 22, 2006) with wide public and political support.

The crucial question for planners and politicians in other cities considering congestion charging is whether the experiences in Stockholm and London are transferable. Is the sudden and, in both cases, unexpected swing in public support an exception or a rule? One way to answer this question is to study what underlying factors determine individual voters' attitude to the congestion charges *after* their introduction. Attitude data from Stockholm allows us to study a situation where the population *is* in fact familiar with congestion charges—the concept, its effects on traffic and environment and its impact on their daily life. It allows us to analyse the question posed above in this sense: assuming that congestion charges have been introduced, what are the decisive factors for acceptability *then*, and what levels of support can be anticipated? In particular, how important are oft-mentioned factors such as car dependence, satisfaction with the transit system and environmental awareness?

This is the purpose of the present paper. Using attitude data collected after the reintroduction of the Stockholm charges (in December 2007), we analyse how variables such as car dependence, transit satisfaction, education, residential location relative to the toll cordon and attitudes to environmental issues influence attitudes to the congestion charges. Later in the paper, we vary the level of these variables to study what the prerequisites are for obtaining the high support levels observed in Stockholm. Is it for example, as has been hypothesised, crucial to have high levels of satisfaction with the transit system? Is environmental awareness crucial? If car dependence were higher, would this erode the support for the charges?

[1] Quote Gunnar Söderholm, social-democratic head of the Congestion Charging Office during the trial, when (after the trial) describing the local Social Democrats' feelings when the national Social Democratic government more or less forced the congestion charges onto the local Stockholm party district.

Separating out the influence of different socioeconomic variables also lets us explain several earlier observations about which groups that tend to support the congestion charges. For example, looking at aggregate numbers, women and inhabitants inside the cordon tend to support the charges more than average. But after controlling for other variables, such as car dependence, etc., it turns out that this conclusion is no longer valid; instead, the main explanatory factors are attitudes and behaviour—not socioeconomic factors per se.

In Stockholm, the charges were to a certain extent marketed as "environmental" charges. During the trial, the national government used the term "congestion tax", while the City of Stockholm used the term "environmental charges". The charges did certainly have environmental effects in terms of reduced emissions in the inner city, but this effect was dwarfed by the very large effects in terms of congestion reduction. There was a widespread impression, however, that environmental concerns were an important factor for the acceptability of the charges. This is in line with findings in the literature that social norms of this type influence acceptability in general, and that support depends not only on the "objective" characteristics of the measure itself, but also on the defined objective of congestion charges and its perceived effectiveness (Bamberg and Rölle, 2003; Jones, 2003). Moreover, several authors have found that it is not just perceived individual benefits that determine acceptability: perceived *social* costs and benefits can also strongly affect acceptability (Jaensirisak et al., 2003). This means that "re-labelling" congestion charges to "environmental charges" and emphasising their positive effects on air quality may very well have had an impact on acceptability. On the other hand, environmental benefits should not be understated: emissions reductions were indeed considerable. Moreover, several authors have argued that the most important long-term environmental benefit is the reduced need for road investments.

The paper is organised as follows. Section 2 gives a brief recapitulation of the Stockholm charges and its history. Section 3 describes the data and some aggregate results. In Section 4 we estimate the influence of socioeconomic, behavioural and attitudinal factors on the attitude to the charges. Section 5 analyses what levels of support the estimated model would predict under other circumstances—for example, if car dependence or transit satisfaction had been higher or lower. Section 6 concludes.

2. The Stockholm congestion charging system

The City of Stockholm has around 0.8 million inhabitants, and is the central part of the Stockholm county, with a total of 2 million inhabitants. Around 2/3 of the City inhabitants live within the toll cordon, and the rest outside the cordon.

Because of its topology, with lots of water and well-preserved green wedges, road congestion levels in Stockholm are high compared to the city's moderate size. Before the introduction of the congestion charges, the main roads arterials leading to, from and within the city centre had congestion indices typically averaging around 200% (i.e. three times the free-flow travel time). Partly because of this, and partly because of good public transport supply, the transit share is high: 60–65% of all motorised person trips to and from the city centre are made by transit. During rush hours, the share increases to nearly 75%. The public transport system in the county of Stockholm consists of a subway network with 100 stations and over a million trips per day, a commuter rail network with 51 stations and nearly a quarter of a million trips per day, five light rail lines with 98 stations with a bit more than 100,000 trips per day, and large bus network with nearly a million trips per day. Public transport fares are subsidised around 50% of the real average cost.

The Stockholm congestion charging system consists of a toll cordon around the inner city, thereby reducing traffic through the main bottlenecks located at the arterials leading into the inner city. The cost of passing the cordon between 6.30 and 18.30 weekdays is 20 SEK (approx. 2€) during peak hours (7:30–8:30, 16:30–18:00), 15 SEK during the shoulders of the peaks (30 min before and after peak period) and 10 SEK during the rest of the charged period Fig. 1.

The system was introduced on a trial basis during the period 3 January–31 July 2006. The trial period was followed by referendums in the City of Stockholm and in about half of the neighbouring municipalities, originally pushed through by parties opposed to the congestion charges. The referendum in the City of Stockholm ended with a majority for keeping the charges, but adding all votes up, a majority of the voters in the county were against the charges. However, the results could be viewed as a bit skewed, since most of the municipalities where polls showed greater support for the charges did not arrange a referendum at all; in most cases, these municipalities argued that it was up to the city of Stockholm to decide the issue. In the end, the new Liberal–Conservative government decided to reintroduce the congestion charges, earmarking the revenues for road investments but as a part of a more comprehensive, partially government-funded transport investment package including both road and transit investments. The congestion charges were reintroduced in August 2007.

The change in public opinion was for most observers the main surprise of the trial. Support for the charges increased from less than 30% before the trial to just over 50% towards the end of the trial. After the reintroduction in 2007, support increased even more to nearly 70% at the end of 2007 (at the time of the attitude survey used in this paper). The media image also changed dramatically already in the early trial period—from ‘‘Congestion charging: even more chaos for road pricing’’ (*Aftonbladet*, December 22, 2005) to ‘‘Stockholmers love congestion charging – People have realised the advantages – The dirge has turned into hymns of praise.’’ (*Aftonbladet*, January 14, 2006). The proportion of newspaper articles expressing a positive view increased from 3% of trial-related articles during the autumn of 2005 to 42% during the autumn of 2006, while the proportion of negative articles were almost halved from 39% in the autumn of 2005 to 22% in the autumn of 2006 (Winslott-Hiselius et al., 2009).

The system, its history and its effects have been described in detail elsewhere. A description of the system and its effects can be found in Eliasson et al. (2009), and experiences from the design and evaluation processes are described in Eliasson (2009c). A detailed account of the political process can be found in Gullberg and Isaksson (2009), while Isaksson and Richardsson (2009) analyse the strategy to create legitimacy for the charges. Gudmundsson et al. (2009) examine how decision support systems were used. Eliasson (2009b) summarises the main lessons in terms of design, effects, acceptability and political process.

3. Data and aggregate attitudes

3.1. About the survey

The data material comes from a survey conducted by the City of Stockholm in late autumn 2007. The survey covers a broad range of environmental issues—opinions, attitudes and behaviour regarding ‘‘green’’ cars, garbage sorting, noise, air quality, car pools, etc. The main focus is on citizens' experiences of the environment in Stockholm and especially in their own residential area, but the survey also contained some questions concerning the congestion charges.

The survey was a postal survey sent out to 4900 individuals, age 16–79, living in the City of Stockholm. The sample was stratified according to the 14 districts of Stockholm, to ensure a sufficient number of responses from each district. Hence, districts with small populations were oversampled: weights correcting for this have been used for all results and estimations. The final response rate after three postal reminders and a possibility to answer the survey by a telephone interview was 65% or 3040 respondents. A non-response analysis carried out by the City of Stockholm showed that men, young people and immigrants were

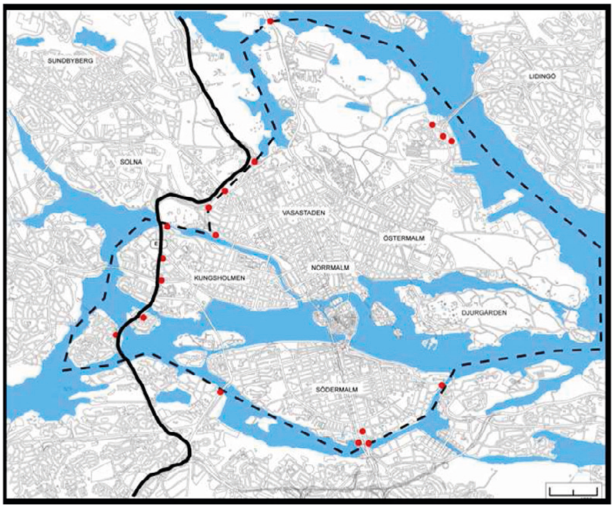

Fig. 1. The charged area. The dashed line is the charging cordon, the dots are charging points and the solid line is the non-charged Essinge bypass.

Table 1
Attitudes to the charges by subgroup.

Segmentation	Subgroup	Size of subgroup (%)	Support (excl. "Don't know/no opinion") (%)	*Very positive* (%)	*Rather positive* (%)	*No opinion* (%)	*Rather negative* (%)	*Very negative* (%)
Total	–	–	66	*27*	*27*	*18*	*13*	*15*
Car ownership	Yes (incl. leased cars)	55	56	*21*	*25*	*17*	*16*	*21*
	No (or only through car pool)	45	78	*35*	*28*	*20*	*10*	*8*
Car dependence; goes by car to work/school…	Always *or* Most of the time	27 [a]	46	*15*	*22*	*19*	*18*	*26*
	Occasionally *or* Never	62 [b]	76	*34*	*29*	*17*	*11*	*9*
Satisfied with transit where I live	Very *or* Rather satisfied	80	69	*29*	*28*	*17*	*13*	*13*
	Very *or* Rather unsatisfied	10	55	*21*	*23*	*20*	*11*	*25*
Residential location	Inner city	41	68	*30*	*28*	*14*	*13*	*15*
	Inner suburbs	31	68	*29*	*24*	*21*	*13*	*12*
	Outer suburbs	28	60	*21*	*27*	*21*	*13*	*19*
Type of housing	House	17	60	*22*	*26*	*20*	*15*	*17*
	Owned apartment	39	68	*28*	*28*	*17*	*12*	*15*
	Rented apartment	44	66	*29*	*25*	*19*	*13*	*15*
Education	Compulsory school	13	58	*19*	*23*	*28*	*14*	*16*
	High school	30	59	*22*	*25*	*21*	*15*	*17*
	University degree	57	70	*32*	*28*	*14*	*12*	*14*
Language at home	Only Swedish	84	67	*28*	*27*	*17*	*13*	*15*
	Swedish and non-Swedish language *or* Only non-Swedish language	16	60	*22*	*22*	*26*	*13*	*17*
Age	16–24 years	10	67	*25*	*26*	*24*	*14*	*11*
	25–44 years	39	68	*28*	*28*	*17*	*12*	*14*
	45–64 years	37	64	*29*	*25*	*16*	*14*	*16*
	$\geq$ 65 years	14	62	*20*	*28*	*23*	*12*	*18*
Gender	Men	47	64	*25*	*29*	*17*	*13*	*17*
	Women	53	67	*30*	*25*	*20*	*13*	*14*

[a] Out of those who go to work or school.
[b] Out of those who go to work or school.

somewhat underrepresented. There may be reasons to suspect that the sample is not representative for the population: people who are interested in environmental issues may be more likely to answer, as are people with strong (positive or negative) opinions about the issues in the survey, including the congestion charges.

This possible "focus/framing" bias is less of a problem in our context, however, since our goal is to study how attitudes to congestion charges vary with (among other things) environmental concerns. Since not everyone chose the most extreme degrees of environmental concerns on any of the questions, the focus/framing effects apparently only shifts the "scale" of the answers in a more environmentally concerned direction. The answers hence still reveal the *relative* strength of environmental concerns among respondents, and this is enough for our intentions—to examine how differences in environmental concern affect support for the charges. The hypothesis that relative levels are preserved is also supported by the fact that stated environmental concerns do indeed correlate highly with support for congestion charges. Had the focus/framing effect been very strong, this correlation would have been erased—but, as will shown later on, it is not.

For the purpose of this paper, the central question in the survey was "What is your opinion about the congestion charges now, after their reintroduction?" The answer alternatives were "very positive", "rather positive", "neutral", "rather negative", "very negative" and "don't know". "Don't know" and non-responses were excluded from the analysis.

The tables in the following sections show responses from different subgroups. To facilitate the overview of the table, the average attitude is summarised in the column denoted "support". This is defined as the share of very or rather positive respondents out of respondents with an opinion (excluding the "neutral" group) (Table 1).

3.2. Socioeconomic and travel-related factors

The most decisive travel-related factor for the attitude to the charges is car availability and car use (recorded as "How often do you go by car to work/school", on a 5-graded scale: always, most of the time, sometimes, seldom, never). After that, satisfaction with the transit system in one's residential area stands out as important. Looking at geographical differences,[2] those living in the outer suburbs are more negative than those living in the inner city (inside the charging zone) and those living in the inner suburbs (adjacent to the charging zone). People living in apartments are more positive than those living in houses.

As to socioeconomic factors, university education, speaking Swedish at home and being under 44 years are associated with a more positive attitude. Females are slightly more positive than men on average.

3.3. Environmental attitudes

The survey also contained several questions regarding environmental attitudes and behaviour. Environmental concerns turn

[2] The residential districts of Stockholm are grouped into three larger areas based on their distance from the city centre and thereby the distance to the charging zone. The inner city consists of districts within the toll cordon, the inner suburbs consists of districts adjacent to the charging zone while the outer suburb consists of districts further away from the inner city.

out to be strongly associated with more positive attitudes to the charges. Below, we list a number of the most useful questions. (The ''support'' is calculated as above, i.e. the share of very/rather positive respondents out of those with either a negative or positive opinion, excluding the ''neutral'' group.) (Table 2).

Clearly, there is a strong correlation between environmental concerns and support for the congestion charges. One should keep in mind that the questions above relate to the *self-image* of the respondent, rather than his or her ''objective'' environmental behaviour. Since the survey was so focused on environmental issues, it is likely that people tend to overstate their environmental concerns and interests, for ''feel-good'' and ''focusing'' reasons. But even given this, the results show a strikingly high level of environmental concerns. For example, virtually no one considers himself to be ''uninterested in environmental issues''. As we argued above, it is likely that there is a focus/framing effect causing the answers to be shifted in the more ''environmentally concerned'' direction—but *relative* preference strengths seem to be preserved. And for the purposes of this paper, it is the differences across individuals we are interested in, not the ''absolute'' level of environmental concerns (if this can be defined).

3.4. Perceived/believed effects of the charges

Respondents were also asked to what degree they believe that the congestion charges have contributed to different positive effects on the traffic situation in Stockholm. A large proportion of the respondents believe that the charges have had positive effects. In particular, a large majority think that they have reduced congestion on roads to, from and within the inner city.

These perceived effects are highly correlated with the attitudes to the charges. The more positive a respondent is, the stronger is the belief in the beneficial effects of the charges. Most likely, this connection is causal in both directions. Strong evidence or own experiences of benefits will likely cause more positive attitude. This is uncontroversial and evidence has been provided by several authors, e.g. Rienstra et al. (1999), Rietveld and Verhoef (1998), Bartley (1995), Harrington et al. (2001) and Thorpe et al. (2000). But there may also be a connection in the other direction: that a respondent with a positive attitude may be more inclined to believe that the charges have had beneficial effects. As Rienstra et al. (1999) concludes, claiming that congestion charging is ineffective can also be a strategic response to justify a negative attitude towards charging. That this latter connection exists is supported by the fact that many respondents – both positive and negative – believe that the charges have decreased noise levels in the inner city. In fact, there is no evidence at all of any such effects (a noise study was carried out during the trial period: Stockholm Stad Miljöförvaltningen (2006)). The fact that many respondents still believe in noise effects can hence neither be explained by own experience nor by measurements reported in the media. The most likely explanations are that respondents either think that they have read something about it, confusing it with other effects (such as congestion and air quality improvements, which were widely reported in the media), or that especially the positive respondents more or less subconsciously *want* to believe that the charges have had beneficial effects (Table 3).

That attitudes affect how the effects are perceived also seems to be a likely explanation of why perceived effects vary so much, despite the fact that citizens were exposed to more or less the

Table 2
Environmental attitudes in the sample, and corresponding attitudes to the charges.

I am [...] in environmental issues.					
	Completely uninterested (%)	Rather uninterested (%)	A little bit interested (%)	Rather interested (%)	Very interested (%)
Share of respondents	1	6	22	50	21
Support for charges within group	46	43	50	70	79
How important is it that you as an individual travel in an environmentally friendly way?					
	Not at all important (%)	Rather unimportant (%)	Neutral (%)	Rather important (%)	Very important (%)
Share of respondents	1	4	10	44	41
Support for charges within group	29	33	39	65	78
Do you worry about environmental issues and the future environmental development?					
	Yes, often (%)	Yes, sometimes (%)	Yes, seldom (%)	No, never (%)	
Share of respondents	32	50	13	5	
Support for charges within group	76	66	52	44	

Table 3
Beliefs about the charges' effectiveness, split by attitudes to the charges.

Do you think that the congestion charges have...	Total (%)	Very/rather positive to charges (%)	Very/rather negative to charges (%)
...decreased congestion on arterials to/from inner city	73	92	48
...decreased congestion within the inner city	74	92	49
...improved the air quality in the inner city	72	89	47
...decreased the noise in the inner city	65	82	40
...improved the public transit to/from the inner city	53	70	29
...caused more people to choose public transit to/from the inner city	42	54	22

Percentages refer to the share of respondents answering ''*Yes, to a large extent*'' or ''*Yes, to some extent*''.

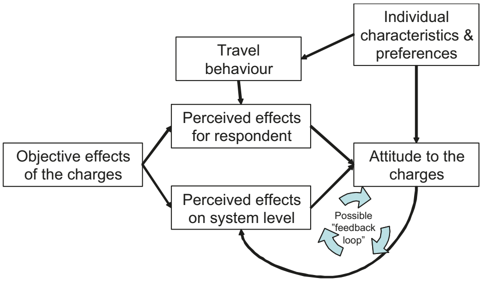

Fig. 2. Factors affecting attitudes to the charges.

same objective reality and the same media coverage (with a certain variation, of course). The reasoning is illustrated in the flowchart (Fig. 2).

The objective effects of the charges cause two types of perceived effects. First, there are effects on the respondent himself, in terms of changed travel costs and travel times and possibly an improved urban environment. Naturally, these effects depend on the respondent's travel behaviour, which in turn are affected by her characteristics and preferences. These are the types of effects that the classical political-economy-oriented literature on acceptability focuses on, where support and resistance to charges are analysed and explained by the individuals' personal costs and benefits. But attitudes to the charges are also influenced by two other groups of effects. One is the system level effects, not directly affecting the respondent. Previous research has shown that not only direct effects but also system effects affect attitudes (see Jaensirisak et al., 2003; Bamberg and Rölle, 2003; Jones, 2003), and later on, we will show evidence of this as well. Finally, attitudes also depend directly on individual characteristics and preferences, such as political and environmental attitudes. Hårsman and Quigley (2010) show that results in the congestion charging referendum in Stockholm were affected not only by personal costs and benefits, but also directly by voters' political preferences in terms of what political party they voted for. This can be interpreted in two ways: political affiliation may act as a proxy for other preferences and attitudes, or political affiliation may affect the attitude to charges directly. Either way, it is evident that political attitudes (in a general sense) affects the attitude to charges.

The difficulty of separating out the effects of perceived system effects on attitudes stems from the curved arrow in the flowchart, going from the attitudes to the perceived system effects. This may cause a "feedback loop" between the attitudes to the perceived system effects, where information that strengthens already held attitudes are given more weight, thereby reinforcing the attitudes.

This means that it is far from obvious how an estimated connection between perceived effects and attitudes should be interpreted. It may even be impossible to disentangle causes and effects in this loop. We will return to this question several times further on.

4. Explanatory factors of the attitudes

In the section above, some of the correlations between attitudes and underlying variables were revealed. But since several of these are mutually correlated – transit satisfaction and car use, for example, or education and environmental concern—it is still not clear what the causal relationships really are. In this section, we will explore these causalities more formally by employing econometric methods.

The dependent variable is the 5-graded response to the question "What is your opinion about the congestion charges". This attitude variable is categorical and ordered, so we use an ordered logit model. This model is based on a latent regression. Let y^* be a latent variable, parametrised through a variable vector X and a parameter vector β:

$$y^* = \beta X + \varepsilon$$

y^* is unobserved: what is observed is whether the response y falls within a certain interval $[\mu_i, \mu_{i+1}]$.

$$y = 1 \quad \text{if } y^* \le \mu_1$$
$$y = 2 \quad \text{if } \mu_1 \le y^* \le \mu_2$$
$$y = 3 \quad \text{if } \mu_2 \le y^* \le \mu_3 \ldots$$

Assuming that the error term ε is logistically distributed, the probability of an outcome $y = i$ becomes:

$$\Pr(y = i) = \frac{1}{1+\exp(-\mu_i + \beta X)} - \frac{1}{1+\exp(-\mu_{i-1} + \beta X)}$$

A more comprehensive description of ordered models can be found in Greene (2003).

In the models presented here, the attitude variable is constructed in a way that a more positive attitude is reflected in a higher value of the estimated parameter. Since all the independent variables are categorical, the parameters are only identified up to a factor. Hence, a reference level has to be defined. In the tables below, the reference levels are listed below the variable name.

The regression coefficients in an ordered logit model cannot be given an intuitive interpretation apart from the sign and confidence level. Instead, we will explore the relative impact of different variables in the next section

4.1. Model 1: without perceived effects

The table below presents estimation results from a model containing socioeconomic variables, attitudes and travel-related variables. The larger (more positive) a parameter is, the higher the support for the charges is, relative to the reference level (in parenthesis in the left-most column). Absent from this model are the respondent's beliefs about the effects of the charges—the perceived effects. These will be introduced in the next model (Table 4).

First, it should be noted that the model is estimated without constraints on the parameters for factor levels. In other words, the estimation does not take into the fact that most variable levels are ordered (e.g. "environmental interest" is measured on an ordered scale from "very interested" to "completely uninterested"). Despite this, nearly all factor levels appear with the "correct" relative sign and magnitude, ordering themselves in the logical order (with two exceptions: "Car to work most of the time" has a lower parameter value than "Car to work sometimes", and "completely uninterested in environmental issues" is not significant. The latter is expected, since very few respondents chose this option.). This is a strong result which lends credibility to the model.

Of the socioeconomic variables, education, gender and language in the household are all significant, but the effects are comparatively small. This is in accordance with Schade and Schlag (2003), who, based on a survey conducted in four European cities, conclude that attitudes towards pricing strategies only to a very low extent are influenced by respondents' socio-economic status. The signs are unchanged from those seen at an aggregate level, except for gender and residential area: women are in fact more negative than men when controlling for other variables, and the

Table 4
Estimation results: attitudes to charges as a function of socioeconomics, travel behaviour and environmental attitudes.

Variable (Reference group)	Coef.	Std. err.	*t*	*P* > *t*
Sex (Man)				
Woman	−0.229	0.084	−2.7	0.01
Car availability (Own car)				
Carpool	0.785	0.314	2.5	0.01
No car	0.549	0.102	5.4	0.00
Language at home (Swedish)				
Swedish and other language	−0.322	0.114	−2.8	0.01
Only non-Swedish	−0.504	0.193	−2.6	0.01
Residential area (Outer suburb)				
Inner city	−0.169	0.099	−1.7	0.09
Inner suburb	0.134	0.094	1.4	0.16
Education (University)				
Compulsory school	−0.384	0.118	−3.3	0.00
High school	−0.293	0.096	−3.0	0.00
Car to work/school (Never)				
Rarely	−0.291	0.134	−2.2	0.03
Sometimes	−0.730	0.176	−4.1	0.00
Most of the time	−0.526	0.160	−3.3	0.00
Always	−0.955	0.161	−5.9	0.00
Don't know	−0.827	0.787	−1.1	0.29
Do not travel to work/school	−0.516	0.113	−4.6	0.00
How satisfied are you with public transport in your neighbourhood (Very satisfied)				
Rather satisfied	−0.005	0.094	−0.1	0.96
Neither satisfied nor dissatisfied	−0.366	0.139	−2.6	0.01
Rather unsatisfied	−0.385	0.162	−2.4	0.02
Very unsatisfied	−0.852	0.333	−2.6	0.01
Don't know	−0.430	0.290	−1.5	0.14
Interest in environmental questions (Very interested)				
Completely uninterested	−0.257	0.543	−0.5	0.64
Rather uninterested	−0.967	0.209	−4.6	0.00
A little bit interested	−0.918	0.137	−6.7	0.00
Rather interested	−0.414	0.118	−3.5	0.00
How important do you think it is to travel in an environmental friendly way? (not at all important)				
Rather unimportant	0.211	0.468	0.5	0.65
Neither important nor unimportant	0.560	0.438	1.3	0.20
Rather important	1.158	0.429	2.7	0.01
Very important	1.630	0.433	3.8	0.00
Don't know	1.047	0.507	2.1	0.04
Threshold (μ) parameters				
Cut 1	−1.777	0.453	−3.9	0.00
Cut 2	−0.887	0.454	−2.0	0.05
Cut 3	0.047	0.454	0.1	0.92
Cut 4	1.381	0.454	3.0	0.00

inner-city respondents are slightly (significant only on the 90%-level) more negative than those living in the outer suburbs.

Turning to attitude variables, ‘‘environmental concerns’’ are strongly associated with more positive attitudes to the charges. As noted above, these questions measure the self-image of the respondent, rather than his or her ‘‘objective’’ environmental behaviour (even if these are correlated to a certain extent). Interestingly, it is these ‘‘self-image’’ variables that have the largest explanatory power. The survey also contained questions regarding environmental *behaviour* – choosing a ‘‘green’’ car, sorting garbage, etc. – but these variables turned out to have insignificant effects once the ‘‘self-image’’ attitude variables had been controlled for. Hence, it seems as if it is the environmental self-image of the respondent, rather than his or her actual behaviour in environmental respects, that affects his or her attitude to the charges.

Turning to travel-related variables, results are as expected: less car use, less car availability and higher transit satisfaction are associated with more positive attitudes to the charges. Interestingly, being member of a car pool is associated with a *more* positive attitude to charges (although this group is small). There are several possible explanations for this. It could be a consequence of self-selection where those joining a car pool are the ‘‘greenest of the green’’, with attitudes more environmental friendly than our simple proxies for interest in environmental issues can capture. Another possible explanation could be that those joining a car pool rarely travel by car and only on occasions when they value the advantages of the car high. Thereby they have a higher average willingness to pay for their few car trips compared to the everyday driver that also take the car for trips with a low willingness to pay for a short travel time. The car pool users' willingness to pay the congestion charges to be able to arrive in time and with a short travel time is therefore higher than the everyday driver. Another explanation is that the car pool users, due to the fact that they are being charged every time they borrow a car from the pool, are fully aware of their cost of car usage and thereby see that the charges are only a minor part of the total cost for the trip.

The variable ‘‘satisfaction with public transit supply’’ is meant to reflect the access to public transport in the respondent's neighbourhood. But stating that one is unsatisfied with public transit supply can also be a way of rationalising and motivating one's choice to travel by car. Irrespective of which explanation that dominates, the variable reflects the subjective resistance to switching from car to public transport.

One can note that those not travelling to work or school are more negative than those going to work/school by other modes than car. The individuals that state that they never travel to work or school are to a large extent over 65 years old and thereby retired. This effect could therefore be an age-effect and not necessarily an effect of lacking travel experience during the peak-hours. It should be noted that we only have information on their travel habits for work related trips—not how they travel when it comes to recreational trips or shopping trips.

Interestingly, residential area is barely significant once other factors are controlled for: the difference between "inner city" and "inner suburb" is significant at the 95% level, the difference between "inner city" and "outer suburb" is only significant at the 90% level, but the difference between "inner suburb" and "outer suburb" is not significant. Even more interesting, inner city residents turn out to be *less* positive to the charges, when controlling for other variables—contrary to the aggregate results in the previous section, where inner city residents were *more* positive. The finding that inner city residents are more positive to the charges has been puzzling several analysts and commentators, since inner city residents pay more and get smaller time savings, on average, than residents outside the toll cordon. The results from the model above show that this finding depends on other factors—primarily environmental attitudes, car use and transit satisfaction. (More on geographical and other equity effects can be found in Eliasson and Levander (2006) and Eliasson and Mattsson (2006).)

4.2. Model 2: with perceived effects

As discussed above, there is a complicated interdependence between attitudes and perceived effects. Hence, one should be somewhat wary of including perceived effects as independent variables. At least, one should check what happens to the other estimates when perceived effects are introduced in the estimation.

Estimating the same model as presented above but adding perceived effects on congestion on roads to, from and in the inner city yields a model as shown in Table 5.

The estimated impact of the other variable do not change much. (This is not easily seen from the table directly: to verify this, the marginal effect of each variable must be simulated and compared between models.) Further, most parameters of the various factor levels keep their "logical" ordering in terms of magnitude (with the same two exceptions as before, plus that two of the "transit satisfaction" levels have wrong relative magnitude; the difference between the two levels is not significant, though).

In the table above only two "perceived effect"-variables are included in the estimated model. It is possible to include variables for more perceived effects but it is uncertain whether that gives any more insights into the mechanisms behind the attitudes. The belief in less congestion on the arterials to and from as well as in the inner city is highly significant and as expected is a higher belief associated with a more positive attitude.

The conclusion of this estimation is that perceived effects are, as expected, strongly connected to attitudes, but that including it or excluding it from the estimation does not affect estimates of the other variables much. This is reassuring, since there is little hope of disentangling the causal relationship between perceived effects and attitudes.

5. Predicted support under different circumstances

The parameters in an ordered logit model cannot be interpreted directly. Hence, the estimation results in the models above only show what variables are important, not their actual impact on aggregate attitudes. In this section, we will use the model to "forecast" attitudes to congestion charges under different circumstances. That is, we want to know what support could have been expected in Stockholm if, for example, car dependence or environmental awareness had been higher or lower.

A simple but enlightening test is to examine the model-predicted support for the charges for the extreme values of each variable. These results are shown in Table 6. Obviously, these are extremes, not realistic scenarios—but the table is enlightening in the sense that it reveals the relative importance of the different variables. Later, we will present more realistic ranges of changes in the variables. Just as above, we summarise the model results in the table by showing the support for the charges, adding the "very positive" and "rather positive" groups and excluding the "no opinion" group. The baseline support level is 65%.

The "predicted effect" of changes in one variable must be interpreted with care. First, the variables have different scales: some are measured on a 5-graded scale, and some on a 3-graded scale. Obviously, a 5-graded variable has the potential to have a bigger effect when taken at its extreme value than a 3-graded variable, all else equal. Second, some extremes may be even more unrealistic than others. For example, while one could at least imagine a city where basically everyone went to work by car, it is not realistic to imagine a city where no one does *and* the city still introduces congestion charges. Another example is the "environmental interest" variable: in the sample, less than one percent answered "completely uninterested". A situation where everyone chooses this answer, especially considering the framing effect of this type of survey, seems even more unlikely than most of the other extremes. Third, several of the variables are correlated: changing just one variable, without changing all variables that are correlated with it, is likely to underestimate the true effect. For example, the two "perceived effects" variables, the "environmental interest" and the "important to travel environmentally friendly" variable are all correlated. It is likely that in a hypothetical city where people had higher or lower environmental concerns, these variables would all be affected. Varying just one of these variables at a time will not capture this effect; varying them all at the same time, adding their marginal effects, risks to overstate the effect (at least when looking at extremes, as in the table).

The table reveals that the most important variables are the perceived effects. As has been discussed above, one should be aware of that there is a difference between objective and perceived effects, and that this difference seems to depend on what attitude to the charges one has: The more positive a person is, the more likely it is it that he or she perceives positive effects. But even considering this, it can be concluded that it is important that a charging system is effective to gain acceptance. It needs to deliver what it is supposed to deliver—decreased congestion, improved urban environment or whatever targets have been set up. Not even the most staunch defender of charges will believe that there are large effects if there are, in fact, none to speak of. This conclusion may seem obvious—but in fact, one is often confronted with cities with virtually no road congestion that are nevertheless considering "congestion charges" (there are several current Swedish and international examples of this). Another problem is the reluctance of many politicians and planners to consider "too complicated systems"—sometimes to the point where the system becomes so simplified that it will not deliver the promised congestion reduction (see Bonsall et al. (2007), for a

Table 5
Estimation results: attitudes to charges as a function of socioeconomics, travel behaviour, environmental attitudes and beliefs about effects.

Variable (Reference group)	Coef.	Std. err.	t	$P>t$
Sex (Man)				
Woman	−0.181	0.088	−2.05	0.040
Car access (own car)				
Carpool	0.630	0.375	1.68	0.094
No car	0.425	0.104	4.10	0.000
Language at home (Swedish)				
Swedish and other language	−0.208	0.130	−1.60	0.110
Only non-Swedish	−0.206	0.241	−0.85	0.393
Area (Outer suburb)				
Inner city	0.132	0.105	1.26	0.208
Inner suburb	0.163	0.105	1.55	0.121
Education (University)				
Compulsory school	−0.159	0.139	−1.14	0.253
High School	−0.230	0.099	−2.32	0.020
Car to work/school (Never)				
Rarely	−0.392	0.138	−2.84	0.005
Sometimes	−0.717	0.176	−4.06	0.000
Most of the time	−0.474	0.166	−2.86	0.004
Always	−0.832	0.166	−5.02	0.000
Don't know	−0.771	0.713	−1.08	0.280
Do not travel to work/school	−0.393	0.121	−3.24	0.001
How satisfied are you with public transport in your neighbourhood (Very satisfied)				
Rather satisfied	−0.037	0.097	−0.38	0.704
Neither satisfied nor dissatisfied	−0.249	0.157	−1.58	0.114
Rather dissatisfied	−0.179	0.174	−1.03	0.304
Very dissatisfied	−0.971	0.407	−2.39	0.017
Don't know	−0.702	0.268	−2.63	0.009
Interest in environmental questions (Very interested)				
Completely uninterested	−0.570	0.706	−0.81	0.419
Rather uninterested	−0.855	0.222	−3.86	0.000
A little bit interested	−0.875	0.146	−5.99	0.000
Rather interested	−0.407	0.121	−3.36	0.001
How important do you think it is to travel in an environmental friendly way? (not at all important)				
Rather unimportant	0.128	0.481	0.27	0.790
Neither important nor unimportant	0.538	0.457	1.18	0.239
Rather important	1.104	0.450	2.45	0.014
Very important	1.490	0.454	3.28	0.001
Don't know	1.521	0.536	2.84	0.005
Belief in less congestion to/from the inner city (No, not at all)				
Yes, to a large extent	2.097	0.179	11.75	0.000
Yes, to some extent	1.363	0.144	9.44	0.000
Don't know	1.223	0.255	4.79	0.000
Belief in less congestion in the inner city (No, not at all)				
Yes, to a large extent	2.156	0.179	12.04	0.000
Yes, to some extent	1.135	0.148	7.66	0.000
Don't know	0.515	0.232	2.22	0.027
Threshold (μ) parameters				
Cut 1	0.214	0.478	0.45	0.654
Cut 2	1.351	0.479	2.82	0.005
Cut 3	2.575	0.481	5.35	0.000
Cut 4	4.270	0.485	8.81	0.000

discussion of this). As has been concluded elsewhere (see e.g. Bonsall et al., 2007; May et al., 2002; Eliasson, 2009b), it is imperative to design a charging system carefully, since the created welfare surplus may be very sensitive to design details—one might even create more problems than are solved.

Not surprisingly, car use, car availability and transit satisfaction are important variables. These variables are of course closely connected—the less transit satisfaction, the higher the car use and vice versa.

It is perhaps more surprising that environmental concerns is such an important factor. The attitude variables "it is important to travel in an environmentally friendly way" and "interest in environmental issues" both have large effects on the attitude to congestion charges. It is worth noting that most respondents considered themselves as at least "somewhat interested" in environmental issues, and thought it was at least "rather important" that one, as an individual, tried to travel in an environmentally friendly way. Only 7% considered themselves to be "rather/completely uninterested in environmental issues", and only 5% thought it was "rather/completely unimportant to travel in an environmentally friendly way".

Clearly, the extreme cases shown above are not realistic, for the reasons mentioned above. To give a more balanced illustration of what the support might have been like, had Stockholm

Table 6
Model-predicted support for extreme levels of various variables.

Variable	Minimal support (%)	Maximal support (%)	Range max–min (percentage points) (%)
Perceived effect on congestion on arterials to/from the inner city (3-graded scale)	40 (no effect at all)	83 (large decrease)	43
Perceived effect on congestion in the inner city (3-graded scale)	41 (no effect at all)	83 (large decrease)	42
"It is [important/not important] to travel in an environmentally friendly way" (5-graded scale)	49(not at all important)	71 (very important)	22
"I'm [interested/not interested] in environmental issues" (5-graded scale)	58 (completely uninterested)	72 (very interested)	14
"I'm [satisfied/dissatisfied] with the public transit supply in my area" (5-graded scale)	53 (very satisfied)	67 (very dissatisfied)	14
Travel by car to work/school	59 (nearly always)	70 (never)	11
Car availability	61 (have car)	70 (does not have car)	9
Language in household	62 (only non-Swedish)	66 (only Swedish)	4
Gender	64 (female)	67 (male)	3
Residential area	64 (outer suburb)	66 (inner city)	2
Education	65 (only primary school)	67 (university)	2

Table 7
Model-predicted support for congestion charges under different scenarios.

	Stockholm (%)	Less environ-mental concerns (%)	Less environ-mental concerns *and* less perceived effects (%)	Higher car depen-dence (%)	Very high car depen-dence (%)
Car availability	55			83	96
Car to work always/most of the time	37			54	83
Rather/very satisfied with public transit	81			48	16
Rather/very interested in env. issues	72	41	41		
Rather/very important to travel in an env.-friendly way	85	39	39		
Much/somewhat less congestion in the inner city	80		63		
Much/somewhat less congestion on arterials	80		64		
Support for charges (excl. "no opinion")	**67**	**54**	**44**	**59**	**51**

been different in certain respects, the table below shows the model-predicted support under different circumstances. Each column represents a different "scenario", where several characteristics of the population have been changed. For each such scenario, the estimated model has been used to predict what the support for the charges would be under that scenario. In order to get an internally consistent model, the model above was reestimated combining factor levels that were in the wrong order (listed above). The characteristics of the sample population were changed by drawing individuals at random one at a time with replacement, changing the characteristics of the drawn individual, and doing this until the population characteristics had reached the given targets. To facilitate reading the table, variable levels have been added together. For example, the "car to work" row shows the sum of "always car to work" and "car to work most of the time" (Table 7).

The first column shows the baseline case, i.e. the original Stockholm sample. Compared to many other cities, car use is low, transit satisfaction is high, and environmental concerns are high (although this may partly be due to the framing effect of the survey). In the second column, the variables related to environmental concerns are decreased to about half their baseline level. Support for the charges drop considerably, from 67% to 54%. However, this may actually be an understatement of the effect, since there is a certain correlation in the sample between environmental concerns and the beliefs about the charges' effects. To preserve the same correlation between environmental concerns and level of perceived effects (approximately), the perceived effects should also be decreased. This is shown in the third column. A variant of the "random-draw-and-change" method was used: individuals were drawn at random from the sample (with replacement) and both environmental concerns and perceived effects were changed, in a way that preserved the correlation between the two on the aggregate level. This caused support to drop to 44%. From this it can be concluded that the high level of environmental concern, together with substantial objective effects, is instrumental for the support for the charges.

The fourth and fifth columns show what happens if car dependence is higher. This is modelled by increasing car availability and the share of people going by car to work/ school, and decreasing the satisfaction with public transit. This is also done with the "random-draw-and-change" method, in a way that preserves correlation between the three variables. Increasing car dependency decreases the support for the charges to 59% and 51%, respectively. This is expected; however, compared to our own expectations before the analysis, support stays remarkably high even for high car dependency levels.

6. Conclusions

Several authors have argued that "familiarity breeds acceptability" when it comes to congestion charging. The Stockholm experiences are interesting since it allows us to study a context where citizens are in fact familiar with congestion charges. In particular, we can study what the decisive factors for acceptance are, once the ''non-familiarity'' problem is out of the way. Although many of contributing factors have been identified in previous studies, the current paper contributes by assessing the factors' *relative* impact quantitatively.

The most important factor turns out to be beliefs about the charges' effects, in particular the charges effect on congestion. Even if one should not confuse these ''perceived'' effects with true, objective effects – since these beliefs and perceptions are most likely influenced by the attitudes to the charges – it seems clear that achieving objective effects is necessary to reach acceptance. This underscores the importance of designing the system carefully and only use congestion charges when congestion really is a problem. Moreover, it seems likely that measuring effects and communicating the results through, for example, the kind of scientific evaluation carried out in Stockholm will increase the awareness of positive effects—provided, of course, that there are in fact positive effects.

The second most important factor turns out to be the level of environmental concern. This supports the conviction of the Stockholm politicians wanting to gain support for the charges that it was important to stress the environmental benefits of the charges—not just (or even primarily) the effects on congestion. Interestingly, it seems as if it is not environmental *behaviour* per se that is important, but the *self-image* of being an environmentally concerned person.

Car dependence and transit satisfaction are, as expected, important—but, perhaps somewhat surprisingly, less so than the environmental attitudes. The less car dependant and the more satisfied with transit individuals are, the more positive are their attitudes towards the charges. Stockholm was fortunate in this sense: less than 60% have an available car, less than 30% regularly go by car to work/school, and over 80% are rather or very satisfied with the transit supply in their area. The model simulations indicate, however, that even with a fairly high car dependency, support stays relatively high.

Surprisingly, the residential location zone (inner city, inner suburbs or outer suburbs) hardly matter once the above-mentioned factors are controlled for. This is surprising since the consequences of the charges in terms of, e.g. tolls paid differ quite a lot depending on residential area.

On an aggregate level, socioeconomic factors such as income, sex, education, etc. seems to be important: there are clear differences in support between such socioeconomic groups, when looking at aggregate numbers. But once car dependency, environmental concerns and perceived effects are controlled for, the influence of socioeconomic factors all but vanish.

In conclusion, there seems to be several reasons for the surprising change of attitudes to the charges in Stockholm—from intense public and political resistance to a situation where around 2/3 of the public support the charges, and no political party supports abolishing them. The most important factor was that the charges were indeed effective in reducing congestion and improving the urban environment, together with an ambitious evaluation and communication plan that made these effects widely known. The second most important factor was the high level of environmental concen, together with the communication of the charges' beneficial environmental effects. The third factor, somewhat surprisingly less important than the first two, was the comparatively low car dependence and high transit satisfaction. For cities considering introducing congestion charges, a main lesson is that familiarity is indeed likely to increase acceptability, provided that the charges are in fact effective and that the effects are measured and communicated. Moreover, emphasising the charges' environmental effects is important. After all, many people are ready to suffer inconvenience or increased costs for the environment, while much fewer are prepared to suffer to achieve a more economically efficient use of scarce road capacity. If congestion charges is marketed only in the latter way, then it seems unlikely that they will get sufficient public support.

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Paper IV

Should I stay or should I go?
– How a Swedish tax reform influenced the residential mobility of the elderly

Abstract

A property tax reform in Sweden in 2008 lowered the property tax for especially highly taxed single-family houses and increased the tax on profits from property sales. This lowered the cost to stay in a high-valued house and increased the cost of moving. The paper analyses how this tax reform influenced the housing tenure transitions of the elderly by comparing households that received a small or non-existent tax cut with household that experienced a large property tax cut using a large representative sample of the Swedish population including information from tax assessments.

The results show that the probability to exit homeownership for elderly households decreased after the tax reform in 2008. And more importantly, this probability decreased more the larger tax cut the household received. The effect is not only statically significant, it is also of a substantial size.

Introduction

For many elderly households the house is by far the largest asset. Releasing home equity could give substantial impact on the standard of living for households that are asset-rich but cash-poor. This is especially important if pensions cover a diminishing share of former labour earnings, something that is the situation in many western countries. However, in many countries a large share of older homeowners stays in their large houses and resist this life cycle consumption motivated tendency to downsize, see e.g., Angelini et al (2014) for an European overview. Empirical evidence suggests that even those elderly households that do move, rarely downsize in the definition of moving to a both smaller and less expensive property (Burgess & Quinio, 2020). This has led to a debate in many countries on why the elderly choose to stay in their commonly large single-family houses instead of downsizing to a smaller and less valued residence.

At the same time, many countries, including Sweden, see increasing difficulties for the young and family forming generation to establish themselves on the housing market. In Sweden this has resulted in several inquiries and reports focusing on the difficulties for young adults both to finance the purchase of an apartment or house but also to be able to get access to an apartment in the rental sector, see SOU (2007), SOU (2015) for examples. For American data Cooper and Luengo-Prado (2018) show that young adults around the millennium had lower wealth at age 25 and 30 than their counterparts 20 years earlier. This lack of resources together with rising housing costs makes it more difficult to live alone which explains most of the increase in the share of young adults living with their parents. This can also be seen in young adults "boomeranging" back to their parents, in many cases bringing young adults to worse labor markets relative the market they left (Chan, O`Reagan, & You, 2021). Tighter housing markets as reflected in higher house prices can be expected to delay both entry to the housing market and the formation of partnership (Ermisch, 1999).

Tax rules and legislation on borrowing, such as requirements on down payments, affects both the choice of the elderly to stay or move and the possibilities of the younger to finance a house of their own. Policy changes in the field of property taxes have therefore implications on the housing market for both elderly homeowners and young adults striving for a home of their own.

This study uses a property tax reform that changed the cost of living in a single-family house in Sweden to analyze how this affected the residential mobility of elderly homeowners using information om housing and socio-economic attributes from tax assessments and population registration. The tax reform in 2008 lowered the property tax on especially highly taxed single-family houses in combination with an increase in the tax on profits from property sales. This lowered the cost to stay in a high-valued house and increased the cost of moving. The paper analyses how this tax reform influenced the housing tenure transitions of the elderly by comparing households that received a small cut in property tax with households that experienced a large tax cut. Elderly households often have a low monthly income and low costs related to mortgage payments. The property tax therefore represents a larger share of both income and housing costs for these households compared to younger households living in houses with a corresponding market value. We therefore expect elderly households to be more affected by the tax cut than younger households in their decision if and when to exit from single-family housing. Due to both life cycle consumption smoothing and changing circumstances of life we also expect these households to exit from single-family housing to a larger degree than younger households.

The data used is part of the "Linda"-database, a representative sample of the Swedish population provided by Statistics Sweden. We use variables related to income and payed taxes from the tax assessment together with information on characteristics like age and household size. Respondents are followed for many years and for each individual in the database, information from the tax assessment is also collected for other household members. This makes is possible to calculate income, ownership of single-family houses and taxes on household level and the probability to exit from single-family housing is modeled on household level. Data from the years 1996-2014 are used to construct variables for the years 2002 to 2013 to capture how the probability to exit from single-family housing for elderly households changed during the period. The results show that the probability to exit decreased for all groups after the tax reform but the most for those households that received the largest tax cut.

The paper is organised as follows. After this introduction follows a theoretical background and literature review of what factors that we expect to influence the housing choice of the elderly. Next section gives a brief description of the tax reform that forms the basis for our estimation strategy and how this is utilized in the research design followed by a description of our data set and how central variables like ownership of single-family houses has evolved over time. This is followed by the results from our estimated models, a description of how the tax reform affected the predicted probability to exit from single-family housing and finally conclusions are drawn and discussed.

What can explain the housing choice of the elderly?

In the paper, we aim to contribute to the understanding on how a tax reform influenced the housing choice of the elderly in Sweden. Housing conditions usually change over life and as people get older it is often assumed that they prefer smaller residences moving from owned houses to rented apartments (Helderman, 2007). This transition can be motivated by both standard life-cycle models where individuals aim at smoothing consumption over time, and explanations related to changing preferences and changing socioeconomic attributes. But policies and tax rules also affect the housing choice by the impact on the user cost of living in a single-family house or an owned or rented apartment.

Selling the house to release equity for consumption

The idea behind the life-cycle consumption theory as presented in Modigliani (1966) is that households form a lifetime plan of investments and consumption. During their productive years households saves and invest in a portfolio of assets and accumulates wealth. Later in life, after retirement, this wealth is consumed – thereby smoothing consumption over the life cycle. For homeownership, the requirement for a down payment is a liquidity constraint that hampers the transition into homeownership for the young. Entering homeownership needs accumulation of assets up to the down payment requirement and lowering or removing this barrier can facilitate for young adults to become homeowners, see Brueckner (1986). Once the down payment is accumulated, for homeownership to be the chosen housing alternative the marginal benefit of owning must exceed the marginal benefit of renting. This is true both for the young deciding on entering into homeownership and the elderly deciding on whether to leave homeownership.

For those elderly that have a large part of their wealth tied to their home, consuming their wealth is often dependent on selling their home and move to either a rented apartment or a less valued house or apartment. Selling the house is however not the only way to utilize the wealth that is captured in a house. Instead of selling the house and move, a reverse mortgage could make it possible for elderly households to use some of their wealth that is captured in their homes without having to move. A reverse mortgage is a financial instrument that enables older homeowners to borrow against home equity. The loan requires no payments as long as the borrower lives in the home and the interest is added to the debt. When the borrower moves or dies the house is sold and the bank recovers the loan. With a reverse mortgage, homeowners can release some of their wealth without having to move and use that wealth for consumption - an advantage for many older homeowners with low income, high housing wealth but no desire to move. Despite this, the market for reverse mortgages is small in most countries and almost non-existent in Sweden where reverse mortgages are not offered by regular banks. For elderly households in Sweden, selling the house and moving to either a less expensive owned form of housing (a cheaper house or an apartment in a cooperative housing association) or a rented apartment is therefore the main way to access the wealth captured in a house.

The low demand for reverse mortgages might seem surprising. Dillingh et al (2017) studies the latent demand for reverse mortgages among older homeowners in the Netherlands where reverse mortgages are very rare even though the prerequisites are right; large housing wealth, a well-developed credit market and at least in the future relatively small pensions. A survey on the interest in reverse mortgages shows that a small minority of homeowners is familiar with the concept but after an explanation, over a quarter of the respondents indicate that they are potentially interested in taking out a reverse mortgage loan once retired. The respondents were randomly assigned to one of two surveys with two different proposed uses for the loan - either for personal consumption smoothing or for financially supporting (potential) heirs. For those that wish to leave a bequest, the interest for reverse mortgages is larger when presented with the proposed use to give financial support to heirs.

The will to leave a bequest or help your children financially during old age is another element behind the choice to downsize. The larger the bequest that a household wants to leave, the less is the room to dissave and consume housing wealth. The will to leave bequests therefore reduces the tendency for elderly to move and consume their housing wealth. However, a wish to help with inter-vivo transfers can advance the decision to exit from homeownership. The financial situation of the children can therefore both increase and decrease the probability for downsizing, and the empirical results in Painter and Lee (2009) are contradictory. As housing wealth is the main form of savings for many households, fluctuations in property values affect savings and bequest expectations. Begley (2017) shows based on survey data that house price fluctuations from 2000 to 2010 affected household bequest expectations that may have nontrivial implications for household behavior.

Without the possibility of reverse mortgages, from the perspective of the smoothing consumption over life, home ownership rates should increase as people save and become homeowners and decline as they age and release their housing equity creating a hump-shaped homeownership age profile as in the model in Artle and Varaiya (1978). Their model also shows that the size of the down payment as well as the cost of homeownership compared to renting is central in the decision between homeownership or tenure.

Based on the life cycle model, we expect housing wealth to decrease with age for the elderly along with the decrease in wealth in general. However, bequest motives that reduces the desired amount of consumption and large perceived transaction costs from moving can halter this tendency. Also, the fact that housing is also used for consumption (not only investment), dampens the tendency to move as the desire for housing consumption is not expected to decrease so much by age. Access to financial instruments, as reverse mortgages, that makes it possible to dissave without selling the house should reduce the tendency of the elderly to move from owned housing. The amount of non-housing wealth also plays a role as the need to release housing wealth for consumption purposes is less if other more liquid resources are available.

The role of changing preferences and health status

But not only explanations related to optimal consumption over the life cycle can help explain the housing choices of the elderly and what influence homeowners' tenure transition decisions. Jones (1997) estimates models on the probability to move from owned housing to tenure and conclude that both explanations related to the life cycle hypothesis but also socio-economic factors influence the moving choice. As most empirical studies, his study is based on survey data. Another study using survey data is Painter & Lee (2009) that conclude that low health status and being a single head of the household implies a higher probability to move while age in itself is not related to moving decisions. These results give support to the explanation that changing preferences affect the moving decisions rather than life-cycle consumption smoothing. The choice to move is often related to certain events or demographic shocks, like the death of a spouse or retirement (Feinstein & McFadden, 1989). Also VanderHart (1994) conclude that demographic factors play a more important role than financial factors in the housing decisions of older homeowners. To enable older homeowners to remain in their homes, policies that help them deal with non-financial challenges may be more important than introducing financial instruments like reverse mortgages according to his analysis.

To sum up, changes in household size, employment or health can be assumed to influence the decision to move. The ability to stay is for elderly households with declining health also dependent on the possibility to gain help to deal with the practical care of a house. From a Swedish perspective the introduction of tax reductions for household services introduced in 2007 can have contributed to a higher proportion of elderly households that choose to stay in a single-family house.

User cost-related explanations

A utility maximizing household will choose the kind of housing that together with other consumption options gives the highest utility. Housing characteristics, location and price are important factors behind the choice between owner-occupied housing or tenure as well as between houses in different locations or sizes. For the elderly household that lives in an owned single-family house the transaction cost that follows with a change in housing can be a major cost component.

For a tenant the cost of housing is simply the rent paid, an out-of-pocket cost that is visible and easy to define. The user cost of owning a home is harder to measure and includes both out-of-pocket costs in the form of maintenance, insurance costs, property tax and mortgage interests but also costs that the owner do not see in the list of transactions from the bank account. This includes forgone earnings in the form of opportunity cost of equity and depreciation that are at least partly offset by the appreciation of the value of the home. The user cost is very sensitive to expectations on capital gains from the appreciation of the house, expectations that vary between individuals. The out-of-pocket cost component and the cost component that measures the return from investing equity into homeownership do not need to have the same effect on the housing choice. Due to liquidity constraints and the uncertainty of the appreciation and opportunity cost of equity it is reasonable to assume that out-of-of pocket costs can be of more importance, see Börsch-Supan (1986). The property tax is one component of the user cost of homeownership for a single-family house that is part of the out-of-pocket cost for the household. A reduction in property tax for single-family houses decreases the user cost of homeownership and makes homeownership more attractive compared to both owning and renting an apartment.

Even though the cost of homeownership relative to renting should be an important factor behind the housing choice, many studies on housing choice of the elderly ignores how housing costs, both in the current house and alternative forms of housing, affects moving decisions. An exception is Shan (2010) who analyses whether higher property taxes in the US has led to increased mobility among elderly homeowners. As the property tax is related to property values the price increase during the late 1990´s and early 2000´s in the US also led to increased property taxes. In public debate, this has been suggested to force elderly homeowners to sell and move due to liquidity constraints. Shan (2010) uses panel survey data on household level for information on mobility (question whether they have moved since last interview) and socio-economic characteristics including property tax. The results in Shan (2010) show that the property tax influences elderly homeowners' moving decisions where a $100 increase in annual property taxes leads to a 0.73 percentage point increase on average in 2-year mobility rates, which represents an 8 percent increase from a baseline 2-year mobility rate of 9 percent. However, it should be noted that revenues from the American property tax are used for local service, especially schools, creating a relationship between property tax and the quality of local service and especially local school quality. As elderly homeowners do not consume school services, they might find that the property tax they pay exceed the service they receive and choose to move to a neighborhood with both lower public service and lower property taxes. The correlation between high property taxes and good public services thus creates an endogeneity problem. To address this endogeneity problem the variation in tax relief programs is used as an instrument for property tax payments in the estimations. The fact that the Swedish property tax level is decided on the national, instead of the local level means that the endogeneity problem that occurs for studies on the relation between property tax level and housing choice in the U.S. is not a problem here.

Only considering the direct effect from a tax cut on out-of-pocket user cost of housing the tax cut is expected lead to a larger share of elderly households that choose to stay in their single-family houses. There is however also an indirect effect from the effect on house prices that can lead in the other direction.

From a theoretical perspective a decrease in property tax should capitalize in property values, as the present value of a property is a function of its discounted explicit or implicit rental value net of expenses in the form of maintenance and taxes over the life of the property. Using the nomenklature of (Yinger, Börsch-Supan, Bloom, & Ladd, 1988):

$$V = \frac{R}{r + t}$$

Where V is the price of a property, R is annual rental value that is a function of the characteristics of the property, t is the property tax and r is the households real discount rate. By estimating this equation (often after taking the natural logarithm for easier estimation) the value of the coefficient for the tax variable can be interpreted as the degree of capitalization divided by the discount rate, making the calculation of capitalization dependent on assumptions on the real discount rate. To what degree a change in property tax is capitalized in the price is an empirical question that gives varying answers, from Church (1974) that finds for American data in late 1960:s that the tax was overcapitalized to studies showing a low or even unexisting capitalization. For the Swedish tax reform that is analysed in this article no effect at all on house prices has been found due to the cut in property tax according to Elinder and Persson (2017) for the vast majority of properties affected by the introduction of the cap. Those 1 percentage most valued houses (that also received the largest tax reduction) only saw an effect on prices that was around half of what could be expected from theory.

However, if the decrease in property tax at least partly was capitalized in property values this would increase the part of the user cost that is related to the opportunity cost of equity and thereby contribute to a lower rate of single-family housing among these households. Since the tax cut was largest for the most valuable houses also the price increase and the increase in opportunity cost and thereby the reduction in single-family housing (and increase in the probability to exit from the same) would be largest among the households living in the most valued houses. I.e. this indirect effect from a capitalization of the tax cut into property values would go in the opposite direction compared to the direct effect from lower out-of-pocket user cost from the tax cut. We do not look at the capitalization in this paper but only note that if the tax cut to a large degree was capitalized this means that the relationship we model between the tax change and the change in the probability to exit from single-family housing is a joint effect from two different mechanisms going in opposite directions.

Estimating the effect on residential mobility from the tax reform

The tax reform in 2008 changed both the property tax, the tax on capital gains from property sales and introduced an interest on postponed profits. All these changes together lowered the cost to stay in a single-family house and increased to cost of moving. However, the decrease in property tax varied depending on initial property tax and this variation is utilized to analyze how the property tax reduction influenced the residential mobility of elderly households.

The tax reform in 2008

Before 2008 the property tax for single family houses in Sweden was a fixed proportion of the tax value. The tax value is assessed based on sales of nearby properties and self-reported indoor and outdoor quality of the building and location and should correspond to 75% of the market value of both land and buildings. Until 2008 the yearly property tax was 1 percentage of this tax value. However, the property tax was limited to a maximum of 4% of the household income for households with a total income below 600 000 SEK conditioned on a not to high tax value and permanent residence. Profits from house sales were taxed to 20% and the tax payment could be postponed without interest if the household bought a new residence.

In 2008 the property tax was reduced to 0.75% of the tax value[1]. More importantly, a yearly cap was introduced that in 2008 was set to 6 000 SEK. All houses with a tax value above 800 000 SEK were therefore taxed to less than 0.75% while houses with a tax value below 800 000 SEK were taxed at the tax level of 0.75%. At the same time the tax limit at maximum 4% of household income was restricted to those above 65 years old or with a sickness pension. Also, the tax on capital gains from real estate was increased from 20% to 22% and interest was introduced on the amount that was postponed from taxation, thereby increasing the cost of moving. For apartments in cooperative housing associations, the property tax is not related to the market value but instead to the value of a tenant house with controlled rents, leading to a very weak relation between market value and property tax and in general a low property tax. Also for apartments in cooperative housing associations, the reform in 2008 led to a lower property tax but the decrease was in general much lower than the decrease for single-family houses as the property tax was not related to the market value, either before or after the reform.

The tax reform decreased the cost of living in single-family houses and increased the cost of moving. However, the introduction of the tax cap meant that the tax reform gave very different changes in property tax for different household based on the tax value of their house. The cost of living decreased for most homeowners but to very different degrees and this variation in cost reduction is used in the paper to explore how the decrease in property tax influenced the moving decision for elderly homeowners.

Research design – three groups of households

The paper focuses on how the tax reform and especially the reduction in property tax in 2008 has affected the residential mobility of elderly homeowners. Several changes in taxation were made in 2008, of which the introduction of interest rate on postponed profits and increased tax on profits from property sales also are expected to affect the moving behavior. To distinguish the effect of the cut in property tax, we look at the propensity to move for different groups that were affected differently by the change in property tax. The three groups are presented in the table below.

[1] See Prop. 2007/08:27 (Government proposal)

Table 1. Description of the three groups of households

	Group 1	Group 2	Group 3
Taxable value in 2007	More than 800 000 SEK	Less than 800 000 SEK	Can be both above and below 800 000 SEK
Income reduction before 2008	No	No	Yes
Income reduction after 2007	No	No	In some cases, but not for all.
Tax reduction in 2008	From 1% of taxable value to 6 000 SEK	From 1 to 0.75% of taxable value	Depends on both income and taxable value

The first group consists of households that payed full property tax in years before 2008 and where the tax value was so high (above 800 000 SEK) that they in 2008 payed the maximum annual property tax of 6000 SEK. The size of the reduction varies within the group depending on the tax value, where those with the highest valued houses also received the largest tax reduction.

The second group consists of household that payed full property tax before 2008 but had a tax value in 2007 below the cap of 800 000 SEK. These households also received a tax reduction but only of 25 percentage as the tax level was lowered from 1 percentage to 0.75 percentage of the tax value.

The third group consists of those households that payed a reduced tax at 4 percentage of their household income in the years before 2008. Some of these households payed full tax after 2007 while other households continued to pay a tax related to income instead of tax value. However, these household did not receive the same kind of tax reduction as the households in group 1 and 2.

We exclude all households that payed full property tax before 2008 but for one or more years after 2008 had a property tax that was limited to 4 percentage of their income.

For those households that sold their house before 2007 a forecasted tax value is calculated based on the tax value the year the house was sold enumerated by a regional property price index from Statistics Sweden. The grouping is based on this calculated tax value in 2007.

Difference in difference

The probability to exit from single-family housing, henceforth called exit from homeownership, for elderly households is estimated both in the period before the tax reform and after the tax reform. We use the fact that different groups received different tax cuts to look at whether, and to what degree, the reduction in property tax changed the probability to move from a single-family house. To do this we estimate Difference-in difference (DiD) models for the three groups of households of the probability to exit from owning a single-family house using a logit function.

$$P(exit\ homeownership)_{it} = \beta_0 + \beta X_{it} + \delta G_i + \gamma T_t + \theta G_i * T_t + \varepsilon_{it}$$

G represents how the household was affected by the tax reform in 2008 that defines our groups. *T* represents time dummies that distinguishes between the period before and after the tax reform and *X* represents other characteristics for the households that affect the probability to exit homeownership. *X* includes household income, household size, changes in household size and age.

Two different types of DiD-models are estimated. The first models only compare how the probability to exit homeownership has evolved for the three different groups over the years using group- and time dummies. In these models *G* represent dummies, those who received a large tax reduction, those with a smaller tax reduction and those that payed an income reduced property tax before 2008. The second group of models instead use the tax change after the reform to interact with the time dummies to see if a higher tax reduction is related to a higher decrease in the probability to end homeownership. In these models *G* represent the real tax change that the reform implied for the household (or the tax change that would have occurred for those households that did not own a house in both 2007 and 2008).

Data

The data used in the statistical analysis is part of the ”Linda”-database, a representative sample of the Swedish population provided by Statistics Sweden. We use variables related to income and payed taxes from the tax assessment together with information on characteristics like age, sex, marital status and number of children living in the household. Respondents are followed for many years and for each individual in the database, information is also collected on all household members. This makes is possible to calculate income, ownership of single-family houses and taxes on household level. Data from the years 1996-2014 are used to construct variables for the years 2002 to 2013.

The database gives information on individuals, but all individuals can also be connected to their household members. This enables estimation both on individual and household level. Since the decision to move and sell a house affects the whole household it should also be a decision made on household rather than individual level. This a motivation for estimating the models based on household rather than individual data. The property tax variable in our data is also based on individuals and their individual share of ownership. This means that for a property owned by two people in equal parts, both the property tax and the taxable property value will be based on half the property's value. In the same way, both property tax and taxable property value will be the sum of two properties in the case when a person owns two properties. We therefore estimate the models using households rather than individuals as our observatory unit.

We are interested in the elderly's exit from the single-family house market and how it changed with the tax reform in 2008 for different groups of single-family house owners based on the tax change they received. We therefore focus on households with at least one household member at the age of 65 or more. We use a setting where new households enter the sample when they become old enough to meet the age requirement. To be included in the estimation the household must however be a homeowner also six years before. This means that a household cannot enter the sample by buying a property within 5 years before the year that we model the exit.

Table 2. Number of observations in Linda

Year	Individuals			Households		
	All			All		
		Whereof aged 65+			Whereof aged 65+	
			Whereof houseowners			Whereof houseowners
2002	787 973	81 905	32 747	303 652	59 261	29 068
2003	791 141	82 236	33 585	305 633	59 444	29 536
2004	794 386	82 845	34 388	307 687	59 918	30 017
2005	797 654	83 402	35 402	309 833	60 397	30 707
2006	803 514	84 405	36 262	312 910	61 138	31 238
2007	810 222	86 047	37 702	316 506	62 334	32 174
2008	817 791	88 071	37 698	320 393	63 718	32 166
2009	825 469	104 126	42 511	323 864	78 839	36 202
2010	833 432	107 599	46 619	327 854	81 291	38 893
2011	838 955	110 852	49 034	330 968	83 650	40 307
2012	845 939	114 096	51 444	334 515	86 002	41 646
2013	853 975	117 139	53 556	337 818	88 103	42 677

Variables

Property tax and tax value

The tax reform did not only reduce the property tax, it also renamed the tax to a fee. In this article we use tax as the name throughout the whole period but in the database the property tax is represented by different variables over the years. The taxable property value (tax value) is also calculated based on different variables in the Linda-database. The tax value is from 2008 and onwards capped at the maximum value that the property tax is based on. This means that we do not know the full property value for houses above this cap after 2008. For those paying a reduced property tax due to low income, we know the size of the reduction as well as the full tax level.

Exit from homeownership

We use the knowledge of if a person pays property tax for a single-family house the current and following year to find those individuals and households that move from an owned single-family house to some other kind of residence. Exiting homeownership is thus defined as ceasing to pay property tax for a single-family house. The property tax must be paid by the person who owns the property on 1 January of the current year, which means that a person who sells a property during the year still pays the entire property tax according to the tax assessment and our database. The buyer does not start paying property tax until the following year. Exiting homeownership according to our definition occurs when a household moves from owning a single-family house to owning an apartment in a cooperative housing association or when moving to a rental apartment. We cannot distinguish between vacation houses and houses for permanent living and exiting homeownership thus occurs also for households living in an apartment that cease to own a vacations house. A household that own both a house for permanent living and a vacation home and sell one of their houses will however not be identified as exiting homeownership. Using variables related to property tax for single-family houses, means that we cannot track those households that downsize by moving from one large owned single-family house to another smaller single-family house. Since the study focus on the elderly's exit from the single-family house market in relation to changes in the property tax for single-family houses, this is a minor problem.

An alternative method that has been considered is to use variables related to gains or losses from property sales to capture the exit from single-family housing. From 2005 we have access to information om capital gains and losses from selling a home. This however also includes sales of apartments in cooperative housing associations that cannot be distinguished from capital gains from sales of single-family houses. Using these variables, we cannot include individuals that transfer their ownership in other ways than selling, for example through gifts or as a part of the division of joint property related to a divorce. The results showed in the rest of the article are based on models using the information on property tax to define homeownership. In that way we are not restricted to the period from 2005 and onwards.

Socio-economic variables

We utilize information on income from work, capital gains and social security payments. The link between household members makes it possible to calculate income and payments on household level. The household link is missing for non-married couples without children living in multi-family houses but since this study only looks at households living in single-family houses the database can link household members as long as they are registered as living in the same house.

Description

Homeownership for different age groups

We start by looking at how homeownership has changed from 2002 to 2013 for different age groups. Starting at looking at the whole population we see that the share of both individuals and households in our database that own a single-family house has decreased over the period. For the elderly the share of homeowners has however increased for individuals, see Table 3. The first three columns show the share of individuals that owns a single-family house while the last three columns instead show the share of households with at least one household member that owns a single-family house, including households with only one household member.

Table 3. Homeownership rate over time for individuals and households

Year	Homeownership rate - individuals			Homeownership rate - households		
	All	Above 64 years	Above 74 years	All	At least 1 household member above 64 years old	At least 1 household member above 74 years old
2002	32%	40%	31%	53%	49%	39%
2003	32%	41%	30%	53%	50%	38%
2004	32%	42%	31%	53%	50%	39%
2005	32%	43%	32%	53%	51%	39%
2006	32%	43%	33%	52%	51%	40%
2007	32%	44%	33%	52%	52%	40%
2008	30%	43%	33%	49%	51%	40%
2009	30%	41%	32%	49%	46%	39%
2010	31%	44%	30%	49%	48%	34%
2011	31%	45%	32%	49%	49%	36%
2012	31%	46%	33%	48%	49%	36%
2013	31%	46%	33%	48%	49%	37%

Three groups of homeowners

The estimation is based on three different groups of households, those paying full tax with a taxable property value above the cap introduced in 2008 (G1), those paying full tax but below the cap (G2) and those with a reduction in property tax due to a low income in relation to the tax in the period before 2008 (G3).

The table below present mean values for taxable property value (tax value), property tax and disposable household income for these three groups of households with at least one household member above 64 years old the current year. The tax value is only presented for the years before 2008 as the tax value is capped in our dataset after 2007. The tax values for 2004-2007 are presented in the price level of 2007 using regional price indexes for single-family houses.

Table 4. Mean taxable property value, property tax and disposable income for the three groups of households, thousands SEK

Year	Taxable property value (tax value)			Property tax			Disposable income		
	G1	G2	G3	G1	G2	G3	G1	G2	G3
2002	1297	403	1045	13,6	4,0	8,3	431	235	187
2003	1323	398	1064	13,5	4,0	9,0	402	246	201
2004	1380	405	1097	13,9	4,1	9,3	429	255	204
2005	1446	405	1141	15,3	4,1	9,5	408	245	167
2006	1209	374	904	12,5	3,8	7,6	474	267	177
2007	1211	364	916	12,7	3,7	7,8	506	280	196
2008				7,9	3,5	5,5	517	296	220
2009				8,6	4,1	5,9	505	287	225
2010				8,7	4,0	6,0	519	287	223
2011				8,8	4,1	6,0	536	304	242
2012				9,2	4,5	6,3	548	322	262
2013				9,6	4,6	6,5	582	329	273

The taxable value differs substantially between the households that received a cap on property tax and taxable value in 2008 (G1) and those that did not (G2). The cap was set to 800 000 SEK and as can be seen the mean property value for those capped was about 1 200 000 SEK in 2007. Those that was not affected by the cap had a mean assessed value at less than half the cap. This difference can both be due to large differences in property values but also differences in the share of household that owns several properties. Both the taxable value and the property tax is calculated as the sum for the household members, not for each property. The property tax is substantially decreased between 2007 and 2008 for those with assessed values above the cap while also the other groups saw smaller decreases in property tax.

Table 5 presents the share of elderly households that exit from homeownership each year 2002-2013, for each group. The year 2007, the last year before the tax on capital gains was increased, as much as 11 percentage of the households with a taxable value below the cap (G2) exited from homeownership, more than twice as many as the years before. For the households with a higher taxable value above the cap and those with a reduced property tax, the increase in 2007 was much less.

Table 5. Share that exit homeownership among households with at least one household member 65 years or older.

Year	G1	G2	G3
2002	6,2%	4,5%	1,2%
2003	6,0%	4,0%	2,9%
2004	3,2%	4,0%	2,6%
2005	4,2%	4,9%	3,9%
2006	2,0%	5,0%	4,3%
2007	3,1%	11,3%	5,1%
2008	2,5%	4,3%	3,6%
2009	2,1%	3,4%	3,6%
2010	2,2%	3,4%	3,2%
2011	2,0%	3,4%	3,5%
2012	1,9%	2,9%	2,5%
2013	1,7%	3,0%	2,6%

Just looking at the shares of households that exit from homeownership gives a picture of decreasing shares of the homeowners that cease to own in the period after the tax reform. The next section looks deeper into what influences the probability to exit homeownership and the role of the tax reform.

Results

We start by estimating a model on the probability to exit from homeownership for elderly households that owned a single-family house 6 years earlier to get a general picture on how the probability have evolved over the years 2002-2013 and how socio-economic variables affect this probability. This basic model that ignores the influence from the tax reform includes variables for household size, a dummy for if household size is reduced the current or prior year, the age of the oldest household member and disposable household income in logarithm together with yearly dummies. This simple model is presented in the second column (model 1) in Table 6.

The results show that household size in itself does not significantly influence the decision to exit homeownership, but a reduction in household size does. A higher income is associated with a lower probability to exit homeownership and households with older household members have a higher probability to stop owning a house. All these results are in line with earlier research.

Looking at the year dummies we can see a tendency that the probability to exit homeownership decreases over the period, where the reference year is 2003, except for 2007 that is the year with the highest probability to end homeownership. The tax reform in 2008 increased the tax on gains from sales which should have advanced some sales to 2007 instead of later years. In the years after 2008 also other changes has been made that have influenced the possibilities to move for elderly households including amortizing requirements on new loans and higher income requirements from the banks. The low Pseudo R^2 shows that the explanatory variables can only explain a small fraction of the decision to exit from homeownership. This is not surprising, the decision on when to move from an owned single-family house to some other kind of housing is not so much a function of the yearly variables that a tax assessment can capture, such as age or income, but instead probably depends on personal circumstances like health and changing social network. However, estimating these kinds of models can still give knowledge on how the tax reform changed the probability to exit homeownership, something done in the other models presented in Table 6.

The influence from the tax reform

This first simple model gives a picture of lower probabilities to exit homeownership in the years after the 2008 tax reform compared to the years before. In model 2-5 we compare how the probability to exit homeownership has evolved for different groups of households depending on how they were affected by the tax reform.

Comparing the three groups

We start with models that only compare the three different groups: 1) those with a taxable value above the cap; 2) those with a taxable value below the cap, and; 3) those that prior to 2008 paid a property tax that was related to their income rather than property value. The reference is group 2 that are the by far largest group and the year of reference is 2003. Note that the change in property tax between 2007 and 2008 depends on both the tax reform and how the assessed value changed. This means that a household could in fact receive a tax increase if the assessed value increased substantially, with at least 33 percentage.

Table 6. Regression results DiD for three groups

	Model 1	Model 2	Model 3	Model 4 – only Stockholm and Gothenburg
Household size	-0.00214	-0.511***	-0.503***	-0.453***
	(0.0225)	(0.0330)	(0.0333)	(0.108)
Reduction in household size (dummy)	0.202***	0.332***	0.328***	0.386*
	(0.0441)	(0.0502)	(0.0504)	(0.173)
Ln disposable household income	-0.375***	-0.342***	-0.356***	-0.384**
	(0.0298)	(0.0364)	(0.0371)	(0.129)
Age oldest household member	0.0324***	0.0321***	0.0323***	0.0125
	(0.00159)	(0.00182)	(0.00183)	(0.00636)
Group 1 – Full tax and taxation value above cap		0.824***	0.806***	0.865**
		(0.112)	(0.112)	(0.268)
Group 3 – Reduced tax before 2008		-0.555***	-0.573***	-0.674
		(0.127)	(0.127)	(0.359)
2002	0.00913	0.0503	0.0484	-0.332
	(0.0477)	(0.0632)	(0.0632)	(0.219)
2004	-0.0771	-0.0342	-0.0329	-0.246
	(0.0490)	(0.0651)	(0.0651)	(0.218)
2005	-0.149**	-0.0834	-0.0847	-0.869**
	(0.0500)	(0.0661)	(0.0662)	(0.269)
2006	-0.207***	-0.0293	-0.0278	-0.246
	(0.0513)	(0.0664)	(0.0664)	(0.224)
2007	0.784***	0.981***	0.984***	0.953***
	(0.0427)	(0.0556)	(0.0556)	(0.180)
2008	-0.328***	-0.164*	-0.161*	-0.609*
	(0.0553)	(0.0721)	(0.0722)	(0.262)
2009	-0.466***	-0.309***	-0.303***	-0.416
	(0.0574)	(0.0750)	(0.0750)	(0.247)
2010	-0.459***	-0.265***	-0.262***	-0.429
	(0.0557)	(0.0716)	(0.0716)	(0.241)
2011	-0.451***	-0.270***	-0.266***	-0.669**
	(0.0556)	(0.0718)	(0.0718)	(0.257)
2012	-0.509***	-0.315***	-0.311***	-0.757**
	(0.0564)	(0.0726)	(0.0727)	(0.266)
2013	-0.492***	-0.284***	-0.284***	-0.438
	(0.0561)	(0.0717)	(0.0719)	(0.242)
*Group 1 * 2002*		-0.0303	-0.0285	-0.00156
		(0.157)	(0.157)	(0.405)
*Group 1 * 2004*		-0.632***	-0.632***	-0.548
		(0.175)	(0.175)	(0.430)
*Group 1 * 2005*		-0.985***	-0.984***	-0.180
		(0.189)	(0.189)	(0.465)
*Group 1 * 2006*		-1.668***	-1.668***	-3.179**
		(0.223)	(0.223)	(1.047)
*Group 1 * 2007*		-2.116***	-2.116***	-2.864***
		(0.178)	(0.178)	(0.531)
*Group 1 * 2008*		-1.344***	-1.345***	-1.337*
		(0.203)	(0.203)	(0.564)
*Group 1 * 2009*		-1.195***	-1.199***	-1.450**
		(0.198)	(0.198)	(0.524)
*Group 1 * 2010*		-1.292***	-1.293***	-1.561**
		(0.191)	(0.191)	(0.522)

*Group 1 * 2011*		-1.428***	-1.427***	-2.456**
		(0.196)	(0.196)	(0.783)
*Group 1 * 2012*		-1.285***	-1.284***	-1.184*
		(0.187)	(0.187)	(0.508)
*Group 1 * 2013*		-1.621***	-1.616***	-1.408**
		(0.201)	(0.201)	(0.480)
*Group 3 * 2002*		-1.167***	-0.0285	-1.990
		(0.246)	(0.157)	(1.078)
*Group 3 * 2004*		-0.0392	-0.632***	0.134
		(0.182)	(0.175)	(0.520)
*Group 3 * 2005*		-0.380	-0.984***	-1.404
		(0.201)	(0.189)	(1.088)
*Group 3 * 2006*		-0.162	-1.668***	-0.587
		(0.189)	(0.223)	(0.638)
*Group 3 * 2007*		-0.955***	-2.116***	-0.744
		(0.178)	(0.178)	(0.481)
*Group 3 * 2008*		-0.481*	-1.345***	0.0628
		(0.220)	(0.203)	(0.617)
*Group 3 * 2009*		0.115	-1.199***	-0.0672
		(0.198)	(0.198)	(0.607)
*Group 3 * 2010*		-0.264	-1.293***	-0.0784
		(0.214)	(0.191)	(0.604)
*Group 3 * 2011*		-0.141	-1.427***	-0.0722
		(0.207)	(0.196)	(0.652)
*Group 3 * 2012*		-0.388	-1.284***	-1.334
		(0.225)	(0.187)	(1.081)
*Group 3 * 2013*		-0.180	-1.616***	0.301
		(0.212)	(0.201)	(0.553)
Constant	-1.030**	-0.869	-0.659	1.394
	(0.395)	(0.472)	(0.488)	(1.738)
Including regional dummies	No	No	Yes	No
Pseudo R2	0.0389	0.0628	0.0640	0.0778
N	287 432	287432	287 361	25 127

Notes: Standard errors within parentheses are corrected for clustering on household. *p < .05, **p < .01, ***p < .001. The sample include households with a disposable income of less than 2 million SEK (excluding capital gains from property sales), a tax value of less than 6 million SEK in 2007 and at least one household member aged 65 or more.

For model 2 (without regional dummies) and 3 (with regional dummies) we can see that for the reference group the probability to exit homeownership is constant until 2007 where the probability increases. In the period from 2008 and onwards the probability is lower than in the period prior to 2007. The reference year (2003), the probability to exit homeownership is higher in the group with high tax values and lower in the group with reduced property tax compared to those with tax values below the cap. Model 4 is estimated using only households residing in the region of Stockholm and Gothenburg, the two regions with the highest property values. For these regions also the year of 2005 stand out with a low probability to exit also among those with a property value below the cap introduced in 2008.

The households that belong to group 1 got the largest tax cut in 2008 and therefore also reduced their cost of staying in their houses the most. We therefore expect these households to have a larger reduction in probability to exit homeownership than the households in group 2. This is also what we see but the development of the probability starts to divert from group 2 already a few years before 2008 when the models are estimated on all regions. Looking only at Stockholm and Gothenburg the reduction in the probability to exit from homeownership starts in the period of the tax reform.

Estimation using the individual tax reduction

While the models in the past section only accounted for whether the households saw a reduction of the property tax from 1 to 0.75 percentage or a higher reduction, we now estimate models where the tax reduction is used more directly. We exclude households that prior to 2008 payed a reduced property tax. The change in tax between 2007 and 2008 is calculated based on the tax value for 2007. This calculated tax change does not take into account any changes in tax value between 2007 and 2008. A positive value means a tax decrease (tax in 2007 minus tax in 2008).

We estimate models where we interact this tax change with a dummy variable for the period after 2007. As we saw in earlier results, 2007 was a year with an extraordinary high proportion of households that left homeownership. Models are therefore estimated both including and excluding the year 2007.

Table 7. Regression Results DiD with continuous treatment

	Model 1	Model 2	Modell 3 – excl. 2007	Model 4 – excl. 2007 only Sthlm and Gothenburg
After 2007	-0.391***	-0.387***	-0.122***	-0.161
	(0.0314)	(0.0315)	(0.0333)	(0.116)
Tax change	0.00000651	0.00000413	0.0000470***	0.0000608***
	(0.00000712)	(0.00000717)	(0.00000589)	(0.0000145)
*After 2007 * Tax change*	-0.000124***	-0.000124***	-0.000167***	-0.000147***
	(0.0000151)	(0.0000151)	(0.0000150)	(0.0000349)
Household size	0.0117	0.0247	-0.00581	0.0108
	(0.0270)	(0.0272)	(0.0310)	(0.0977)
Reduction in household size (dummy)	0.191***	0.188***	0.304***	0.327
	(0.0462)	(0.0463)	(0.0496)	(0.179)
Ln disposable household income	-0.445***	-0.464***	-0.475***	-0.549***
	(0.0329)	(0.0335)	(0.0378)	(0.119)
Age oldest household member	0.0330***	0.0332***	0.0382***	0.0181**
	(0.00168)	(0.00169)	(0.00186)	(0.00644)
Regional dummies	No	Yes	Yes	No
Constant	-0.0159	0.306	-0.183	2.224
	(0.431)	(0.445)	(0.501)	(1.603)
Pseudo R2	0.0392	0.409	0.0387	0.0369
N	249 716	249 651	229 738	18 995

Notes: Standard errors within parentheses are corrected for clustering on household. *p < .05, **p < .01, ***p < .001.

Model 1 and 2 include 2007 in the before period. The tax change variable is not significant, this implies that there a no difference in the probability to exit homeownership in the period prior to the tax change depending on how large the tax reduction in 2008 was. Since the tax reduction is a function of the tax value a large tax change implies a high tax value. The probability to exit homeownership is lower in the period after 2007 and more important, this probability decreases more if the household received a high tax reduction, showed by the negative and significant estimate for the interaction variable between the after 2007-dummy and the tax change.

Model 3 and 4 excludes the year 2007. Comparing model 3 and model 2 we see that excluding 2007 gives a significantly higher probability to exit homeownership with a higher reduction in property tax in the before 2008-period. The effect of the tax change on the decrease in probability in the after-period remains and is even a little bit larger when excluding 2007. Model 4 estimates the same model using only data from Stockholm and Gothenburg and the size of the variable of interest here, the interaction between the after-period and the tax change, is significant and of the same magnitude.

Predicted moving behaviour with and without the tax cut

To get a clearer picture of the significance of the tax change for the tendency to move, calculations have been made on the predicted probability of exiting homeownership in the period before and after the tax reform for households that faced various tax cuts. We use the estimated parameters from models 2 and 3 presented in Table 7. Regression Results DiD with continuous treatmentTable 7 to calculate the predicted probabilities for 3 different households using mean values for all variables except the property tax change that we alternate. We make the calculations for three different levels of the tax cut, 1 000 SEK, 2000 SEK and 6000 SEK. This corresponds to households with a house with a tax value of 400 000 SEK, 800 000 SEK and 1 200 000 SEK in 2008 respectively.

When using the parameters from a model including all years from 2002 to 2013, we see that the probability to exit homeownership is the same, 4.5 % per year independent on the tax value before the tax reform. In the period after the tax reform this probability drops to 1.5 to 2.8 percentage with the largest drop for the household that the received the largest tax cut. We know that the households that had a house with a tax value below 800 000 SEK exited homeownership to a very high degree in 2007 while the extra propensity to exit was not so large for those with a higher tax value. When we exclude the year 2007, using the estimated parameters in model 3 instead, we see that the probability to exit homeownership was higher in the period before 2008 for households with a higher tax value. In the period after the tax reform the probability drops,and also here the most for the households that received the highest tax cut.

The reduction in property tax cannot explain the whole decrease in the probability to move from a single-family house for these elderly households. As explained earlier other tax changes including a higher tax on profits occurred at the same time. However, the probability to exit homeownership decreases more the larger tax cut the household received and the difference between the three different fictious households are quite large even though the variation in tax value are far from extreme, those that received a tax cut at 6000 SEK had a tax value only three times as a high as those that the received a tax cut of 1 000 SEK.

Table 8. Predicted probabilities to exit homeownership for households 65+ before and after the tax reform

Tax cut	**Probability to exit before tax reform**	**Probability to exit after tax reform**	**Difference**
All years (model 2 in table 7)			
1 000 SEK (below cap)	4,5%	2,8%	1,8 %
2 000 SEK (on cap)	4,6%	2,5%	2 %
6 000 SEK (above cap)	4,6%	1,5%	3 %
Excluding 2007 (model 3 in table 7)			
1 000 SEK (below cap)	3,5%	2,6%	0,9 %
2 000 SEK (on cap)	3,6%	2,3%	1,3 %
6 000 SEK (above cap)	4,4%	1,5%	2,9 %

Both the drop between the period before and after the tax reform and the difference in the size of this drop between the household that received a large tax cut (6 000 SEK) and those with a smaller tax cut (1 000 SEK) is quite large. The difference depending on the size of the tax cut is though not only statistically significant, as shown in Table 7, but also with a substantial size.

Conclusion and discussion

The purpose of this paper was to examine the effects of a tax reform that lowered the property tax and increased the tax on profit from property sales on the residential mobility of elderly households. This tax cut in 2008 lowered the cost of living for all houseowners that payed the full property tax unless the tax value was increased more than 33%. The tax cut was however larger, both in absolute numbers and in percentage, for those households with the most high-valued houses. The results show that the households that received the largest tax cuts also decreased their probability to exit from ownership of single-family houses the most after the tax reform. This is what we should expect as these households received the largest decrease in housing costs and is also in line with earlier results of the effect of property tax changes on the moving behavior of the elderly in the U.S presented in Shan (2010). The effect from socio-economic variables on the probability to exit homeownership is also in line with previous research and theory of life cycle consumptions smoothing; the probability is higher for households with older household members, lower income and those households that has seen a reduction in household size.

The tax reform not only meant that property taxes were reduced but also that taxation of profits increased. We cannot determine the profit that would result from a sale because this depends on both the purchase price and the expected sales price, information that are lacking in the data set. However, it is reasonable to expect that the properties with the highest property tax prior to 2008 would also be sold with the highest profits, in absolute numbers, and thus also in absolute numbers get the highest tax increase even if the tax increase as a percentage of the profit is the same for everyone. Since 2007, other changes have also taken place that have affected the costs and opportunities to move for older households. Amortization requirements and stricter requirements for loans introduced by the banks have decreased the opportunities for the elderly with low pensions to be granted a new mortgage, even if the amount is small in relation to the market value of the new home. Mortgage caps in the form of loan-to-value ratios and loan-to-income ratios also affect the possibility to buy a home for the younger generation. The introduction of such mortgage caps from 2010 and onwards should have decreased the homeownership rate for the households where the credit constraints are binding, especially young adults and households with a foreign background (Enström-Öst, Söderberg, & Wilhelmsson, 2017). Increasing credit constraints as well as reductions in income and financial assets followed by the financial crisis in 2008 are other factors that should have affected the demand for single-family houses.

A tax increase on gains from property sales that is notified in advance can be expected to shift sales in time. This can be clearly seen in 2007, where the decided increase in the tax on capital gains in 2008 led to an unusual number of sales just before the tax change. Such anticipatory effects of a tax change have also been observed when the real estate transfer tax increased 2006-2016 in German states (Fritzsche & Vandrei, 2019). The change between 2007 and 2008 is therefore a combination of such an anticipatory effect and a long-term effect from the change in user cost.

Price fluctuations on the house market also affects the number of sales. As Englund (2011) states, when housing markets move from boom to bust, this is usually accompanied with fewer houses offered for sale. This is also what happened in 2008-2009 when house prices fell during the financial crisis (see figure 5 in (Englund, 2011)). A part in the decrease in the probability to exit from homeownership in 2008 and 2009 is probably such an effect from the sudden drop in house prices in the fall of 2008.

The entire change in the elderly's propensity to move that can be seen after 2007 can therefore not be explained by the change in property tax. But the fact that the propensity to move decreased more the larger the tax cut was, implies that a substantial part of the reduction could be explained by the reduction in property tax. We can however not fully isolate the effect from the change in tax regime from other events.

Is it then a desirable or problematic effect of the tax change that the propensity to move decreased among these households? In the political discussion before the tax change, the argument was made that the high property tax forced old people to sell and move. The fact that a tax reduction reduced the propensity to move could therefore be seen as an improvement in welfare for the elderly households with low incomes who would otherwise have moved. However, a large part of the elderly households was covered by a restriction rule which meant that the property tax could amount to a maximum of 4 percent of the income. For this group of households, the probability of exiting homeownership also decreased less after the tax reform than for those paying the full tax. The group that before the tax reform in the debate was identified as vulnerable to the property tax, those with highly valued properties and low income, were thus protected against a high property tax in the relation to their income even before the reform.

Even if the lowered property tax is not the only explanation behind a decrease in the proportion of elderly households that that decide to exit homeownership, the tax cut implied a substantial reduction in housing costs for many households. The size of the remaining housing cost can be hard to determine, both from a researcher perspective and from the perspective of the household. What is really the cost of living in a house with no mortgage payments and where very little money is spent on maintenance? From the household perspective the monthly out of pocket housing cost is often considered as very low, especially compared to the rent of a newly built apartment that is fitted for someone with disabilities. For these households the reduction in property tax implied that a large share of the perceived cost of living in the house disappeared. It is not surprising that such a large relative price change for staying compared to moving have affected the choice to exit from homeownership. While these elderly households have low housing costs staying in their houses, buying the same house would imply a monthly housing cost that are many times larger for a young family that need to finance the purchase with mortgages. A reduced supply of single-family houses due to elderly households staying in their homes increases house prices and thereby further widens the gap in housing costs between these elderly households and those households just entering the market.

By staying in their house without the possibility of additional mortgaging, it is not possible for these elderly households to dissave and consume their wealth. A higher proportion of households staying longer in their houses should therefore lead to larger bequests. As the tax reform reduced the tendency to move the most for those living in the most valuable houses, it is for these households that we expect to see the largest increases in wealth left to their heirs. The tax reform had therefore implications not only for the distribution between different households on the housing market but can also have distributional effects related to bequests. To what degree a postponed exit from homeownership has led to a larger part of the wealth left at death is not explored in this paper. It is however an interesting question for future research.

Rising property values in combination with pensions corresponding to a diminishing share of former labor earnings means that property values are becoming increasingly important for the elderly's financial situation. As Nakajima and Telyukova (2011) modeled, higher property values also mean that the incentives to sell increase and rising property values should therefore lead to a reduction in homeownership among the elderly. In accordance with this, the high price development for single family houses in Sweden during the period we analyze should have led to an increased tendency to exit homeownership. Especially as the possibility to use reversed mortgages to utilize the wealth that is captured in a house is very limited in Sweden. The reduction in the willingness to exit from homeownership after the tax reform that we see could therefore been even larger without the rise in property prices.

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