Centre for Transport Studies STOCKHOLM

Peak Car? - Drivers of the recent decline in Swedish car use

Anne Bastian
Maria Börjesson
Centre for Transport Studies, KTH Royal Institute of Technology

CTS Working Paper 2014:15

Abstract
It has long been well-known that economic variables such as GDP and fuel price as well as socio-demographic characteristics and spatial distribution are key factors explaining car use trends. However, due to the recently observed plateau of total car travel in many high income countries, it has been argued that other factors, such as changes in preferences, attitudes and life-styles, have become more important drivers of car use. This paper shows that the two variables GDP per capita and fuel price explain most of the VKT (vehicle kilometers traveled) trends: as much as 80% over the years 2002 to 2012. The estimated elasticities are well in line with previous literature and can reasonably well reproduce the VKT trend per adult back to 1980. We find, however, a substantial variation between municipalities in terms of elasticity of VKT per adult with respect to fuel price and GDP per capita, depending on public transport supply, population density, share of foreign-born inhabitants and the average income level.

Keywords: Peak Car, fuel price elasticity, GDP elasticity, transport forecasting, car use

JEL Codes: R41, R42, R48

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

1 INTRODUCTION

Since 2008, the car travel per adult has declined in Sweden, as in many other high income countries(Goodwin, 2013; Goodwin and Van Dender, 2013; Millard-Ball and Schipper, 2011). Although it is well-known that economic and demographic factors are important drivers of car use trends, this recent development has led some to argue that other factors, such as changes in preferences, attitudes and life-styles, have become more important drivers of car travel. The OECD (2013) report on trends in car use, applying data aggregated to the country level, concludes that economic downturn and rising fuel prices explain some of the trends in car distances driven in the past decade, but not all. To reach this conclusion, however, the authors make the strong assumption that fuel price elasticity is constant across and within countries, despite strong indication that the elasticities differ substantially between rural and urban residents and between low- and high-income households (Blow and Crawford, 1997; Santos and Catchesides, 2005; Wadud, et al., 2009; 2010).

The purpose of this study is to explore the extent to which economic variables can explain the trends in car travel in Sweden from 2002 to 2012. We estimate the elasticity of VKT (vehicle kilometers traveled) per adult with respect to fuel price and GDP per capita on aggregate time-series data. The analysis reveals the extent to which the temporal changes in VKT per adult can be explained by trends in fuel price and GDP per capita. We allow for different elasticities in urban areas and other regions. The estimated elasticities are also validated on time-series data from 1980. The data is based on distance meter readings of more than two-thirds of the cars in Sweden. This large data set ensures robustness with respect to random variation.

The observed trend break in VKT per adult has been seen as a challenge for travel demand forecasting, the accuracy of which has been questioned (Millard-Ball and Schipper, 2011). The United States Energy Information Administration has reduced their reference case projection of annual VKT growth rates until 2035 from 1.5% (projection from 2010) to 0.9% (projection from 2014). The Swedish state-of-practice forecasting model predicts a corresponding growth of 1.2% annually until 2030 (Swedish Transport Administration, 2014b). This, however, corresponds well with the average yearly increase in VKT from 1999 to 2012 of 1.1%. Still, this trend has by no means been constant. During the years 2008-2012, the VKT fell on average 0.3% per year. This period is also characterized by low GDP growth and increasing fuel prices.

The key question tackled in this paper, the extent to which the economic factors can explain the recent trends in VKT, is a key issue in transport forecasting. Transport forecasting models rely on the assumption that the parameters explaining past travel behavior and preferences remain constant over time (Fox and Hess, 2010). These parameters typically capture responses to changes in economic and demographic variables, such as GDP, fuel price, geographical distribution of firms and population by socio-economic status. Hence to the extent that trends are driven by such variables, a good transport model would have a decent chance of predicting future travel demand as long as the development of these input variables themselves is reasonably well predicted (which is a challenge in itself). To the extent, however, that the trends in VKT are driven by changes in preferences, attitudes and life-styles, transport models would not be able to predict them.

Although there is substantial variation in the literature, estimated elasticities of fuel price elasticities on VKT are usually close to -0.2 in the short run, and -0.7 in the long run (Brons et al., 2014; Dahl, 2012; C. Dahl and Sterner, 1991; Espey, 1998; Goodwin et al. 2004; Graham and Glaister, 2004; Sterner and Dahl, 1992). The distinctions between short-term or long-term elasticities are by no means clear cut, but Goodwin et al. (2004) refer to short-term responses as taking place within a year whereas long adjustments refer to the asymptotic end state, usually taking place within 3-10 years. Based on a literature survey, Hanly et al. (2002) report an average elasticity of real GDP on VKT of 0.30 in the short term and 0.73 in the long run.

The elasticities reported above are average values but vary substantially depending on trip type, individual characteristics (e.g. income) and transport option and land-use. Wadud et al. (2010), Blow and Crawford (1997) and Santos and Catchesides (2005) (the former using US data and the latter two using UK data) find that elasticity is higher among urban residents than for rural. This is plausible given that urban residents have higher accessibility to public transport and a larger variety of destination alternatives. Santos and Catchesides (2005) find that the elasticity of fuel price on VKT ranges from -0.63 for low income urban households to -0.07 for the richest rural residents. Headicar (2013) also finds a stronger recent trend decline in car use in London than in the rest of the UK.

Our econometric model results show that the two variables GDP per capita and fuel price explain most of the VKT trends, as much as 80%, over the years 2002 to 2012. Moreover, the elasticities estimated in the model are well in line with previous literature and can reasonably well reproduce the VKT trend per adult back to 1980. Hence, based on the decline in VKT per adult observed 2002-2012, it is at least too early to draw the conclusion that we are seeing any substantial trend break in the preferences for driving on the aggregate level. The large explanatory power of the two variables, GDP per capita and the fuel price, is reassuring and lends some credibility to transport forecasting.

A caveat of our aggregate analysis is that, in a more disaggregated analysis of our data, we find a substantial variation in GDP per capita and the fuel price elasticities between municipalities. The VKT per adult tends to be more sensitive to GDP per capita in municipalities where the average income is low, and where the public transport supply and population density are high. Lower GDP per capita elasticities in high income and dense municipalities indicates saturation in car travel, in consistency with the analysis of French data by Grimal et al. (2013). Hence, although GDP and fuel price explain most of the aggregate VKT trends on the aggregate level, which provides some credibility for transport models in general, the observed variation provides a warning for very aggregate analyses of car use trends and a call for more in-depth analyses.

2 DATA

To measure VKT between the years 2002 to 2012 we use distance meter readings from passenger car inspections, which are mandatory in Sweden. The data is aggregated per municipality and calendar year and spans from 2002 to 2012. Actual distances driven are recorded for about two-thirds of all cars registered in Sweden, both privately owned and company cars. These observations are used to estimate distances driven for the remaining one-third of cars in Sweden, based on car age, model and ownership type. Among the cars without recorded distances, 60% are less than three years old. The estimated yearly distance of these new cars equals the yearly average distance of the three-year-old cars (within the same class) inspected for the first time. This implies a risk that a fraction of the inter-temporal changes in driving distances lags behind in the data.

The distance of each car is assigned to the municipality where the car is registered. Roughly one-fourth of cars are company cars, which on average are driven about 20% further than cars registered to a person (Statistics Sweden, 2014b). Comparisons across municipalities within the same year may be biased because company cars are sometimes registered in a municipality different from the residence of the user. Comparisons across time are more reliable where the share of company cars per municipality remains relatively stable over time. The municipalities of Solna, Malmö and Lund are excluded altogether from the analysis because of their high concentration of company car registrations.

In this paper, we define urban areas as the 25 municipalities within Stockholm County (excluding Solna municipality) and the municipalities of Gothenburg and Mölndal. The latter two municipalities constitute the Gothenburg urban area. We apply this relatively narrow definition of urban areas, because the extensive public transit networks, labor market size and population density make the Stockholm and Gothenburg urban areas distinct from other parts of Sweden.

Stockholm County (excluding Solna municipality) has 2.1 million inhabitants. Stockholm has a well-developed public transport network including metro, commuter trains, trams and buses. The share of public transit trips to and from the inner city reaches 75% during peak hours. The inner city of Stockholm is built on several islands, connected by bridges, which, before the introduction of congestion charges in 2006, used to imply relatively high road congestion for a city of comparable size. The bridges connecting the inner city to the surroundings are the major bottlenecks in the road network, and congestion charges are levied on these. Gothenburg is Sweden's second largest city. The most central municipalities in this region, Gothenburg and Mölndal, have 590 000 inhabitants in total. The public transport system comprises trams, commuter trains and buses and the road congestion is fairly limited. According to the National Travel Survey the average mode share for car is 30% in Stockholm, 42% in Gothenburg and 63% in the rest of Sweden.

In the present analysis, we focus on the drivers of VKT per adult. Adults are defined as registered residents of Sweden aged 18-84. Population, GDP, average income and license holding statistics are taken from Statistics Sweden. A measure of public transport supply by municipality (defined as vehicle km per square kilometer in 2012) is calculated from a database covering all the timetables of all public transport operators in Sweden. The total vehicle km in a given municipality include all tours that start within the municipality even if they end in another.

The relatively accurate and representative data acquired from car inspections are as described above only available from 2002 to 2012. However, in order to obtain some indication as to whether these elasticities are significantly different from the elasticities that have been prevailing over a longer time, i.e. whether we can identify some trend breaks occurring after 2002 in this respect, we also apply a data of VKT per adult extending over a longer time, from 1980 to 2012. This data is estimated from a number of data sources including gasoline and diesel sales data (SIKA, 2004). The accuracy of this data is not as good as the data from 2002 to 2012, partly because the method of measurement has changed over the years, and this data cannot be broken down by municipality. For this reason, this data is not used for model estimation, but only applied to validate the elasticities estimated with the more accurate data from 2002 to 2012.

We use real fuel pump volume sales prices as provided by the Swedish Petrol and Biofuel Institute (SPBI) as well as the World Bank. We do not consider changes in diesel prices separately. Diesel volume prices in Sweden increased slightly faster than gasoline prices between 2003 and 2008 but have increased at the same rate as gasoline prices since 2009. In 2002, diesel cars accounted for 9% of total VKT, while by 2012 they accounted for 29% of total VKT, and most of the increase took place after 2009 (Statistics Sweden, 2014b). Although we use gasoline prices in this paper, they do reasonably reflect the prices of fuel in general and we therefore refer to them as fuel prices.

In our main analysis, we consider only fuel price and not the cost of driving. The marginal cost of driving usually changes less than the fuel price in the longer run, because some drivers adjust to fuel price increases by purchasing more fuel-efficient vehicles. The elasticity of fuel price is, therefore, higher on fuel consumption than on VKT in the longer run (Goodwin et al., 2004). Moreover, since the beginning of the 2000s, there has been a faster technological development in terms of fuel efficiency than in previous years, implying that new cars are increasingly more fuel-efficient. We explore the extent to which the increase in fuel efficiency and the implied decline in fuel cost per kilometer influence the estimated VKT per adult elasticity with respect to fuel price.

Data on fuel efficiency are acquired from Swedish Transport Administration (2014a), which is based on (HBEFA, 2014). The computation of the average Swedish fuel efficiency is based on the distance driven by car type, car age, and road type. Our data do not, however, take into account effects such as air conditioning, which reduces the fuel efficiency over time as it is more frequently used. Moreover, the efficiency data represent the national average, and cannot distinguish between urban areas and the rest of Sweden.

3 DESCRIPTIVE STATISTICS

3.1. Aggregate national trends

From 2002 to 2007. the total VKT in Sweden increased by approximately 1.4 % per year, but it remained roughly constant from 2008 to 2012. However, between 2007 and 2012, the adult population grew by approximately 1% per year. This means that the VKT per adult declined, by in total 5% between 2007 and 2012.

The period from 2002 to 2012 is marked by strong increases in real fuel prices, 39% in total. Sweden, along with other European countries, has among the highest absolute consumer prices of fuel in the world. In 2012, a liter of gasoline in Sweden cost the equivalent of US $2.10. This is approximately twice the price paid in the United States (World Bank, 2014). The GDP per capita dropped sharply after 2008, but by 2012 was back at the 2007 level.

Figure 1 depicts the trends in VKT per adult, as well as the fuel price and GDP per capita between 2002 and 2012. Figure 2 shows the longer term trends (1980-2012) in VKT per adult, as well as in the gasoline price and GDP per capita. In both Figure 1 and Figure 2, the fuel price index adjusted for fuel efficiency is calculated by multiplying the fuel price and efficiency indices. Data on fuel efficiency are not available for the years before 1990, and we have, therefore, assumed that efficient stayed constant before 1990. Between 2002 and 2012, the average fuel consumption for each driven kilometer declined by a total of 11%. Hence, as the fuel price increased by 39% from 2002 to 2012, the fuel price adjusted for efficiency increased by only 39%*89% = 23%.

As discussed above, the fuel efficiency index is unreliable, given that it depends on traffic conditions and the use of air conditioning. Moreover, it is even less clear what influences the drivers' perception of the driving cost, e.g. the extent to which the driver focuses on the fuel price or the fuel consumption. Because of these uncertainties, the models specified in Section 4 will be estimated both assuming the real fuel price and the real fuel price adjusted for increasing fuel efficiency.

Table 1 summarizes some statistics of the period 2002-2012.

Table 1: Descriptive statistics total Sweden

year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
GDP, in 2012 SEK (10^{12})	2.86	2.93	3.05	3.15	3.28	3.39	3.37	3.2	3.41	3.51	3.54
Gasoline price/l (2014) SEK	10.82	10.72	11.34	12.51	12.8	12.63	13.14	12.68	13.47	14.25	15.02
Diesel price/l (2014) SEK	9.66	8.97	9.72	11.78	12.49	11.8	13.75	12.07	12.89	14.25	14.85
Median Income (2012) SEK (10^5)	2.14	2.16	2.21	2.25	2.28	2.32	2.34	2.39	2.37	2.37	2.42
Adult population (10^6)	6.79	6.82	6.85	6.88	6.94	7.01	7.08	7.17	7.24	7.31	7.37
VKT (10^{10})	5.94	6.03	6.12	6.15	6.2	6.31	6.36	6.26	6.27	6.32	6.28
Cars registered (10^6)	4.12	4.15	4.18	4.22	4.29	4.32	4.35	4.37	4.42	4.48	4.53
VKT per adult (10^4)	0.87	0.88	0.89	0.89	0.89	0.9	0.89	0.87	0.86	0.86	0.85
No cars per adult	0.60	0.60	0.61	0.61	0.61	0.61	0.61	0.60	0.61	0.61	0.61
VKT per car (10^4)	1.44	1.45	1.46	1.45	1.44	1.46	1.46	1.43	1.41	1.40	1.38

The trends in population growth and VKT per adult differ significantly between urban areas and the rest of Sweden (Stockholm and Gothenburg as defined in Section 2), as shown in Figure 1. The statistics are summarized in Table 2 and Table 3. In the urban areas., VKT per adult declined by 8 % from 2007 to 2012, while the adult population grew by 7%. In the rest of Sweden, VKT per adult declined less, 4% over the same period, and the population grew by 3%. Total VKT thus remained roughly stable from 2007 to 2012 in both the urban areas and the rest of Sweden. The number of cars per adult also remained roughly stable between 2002 and 2012, both in urban areas and in the rest of Sweden. Hence, the average distance driven per car declined slightly 2008-2012.

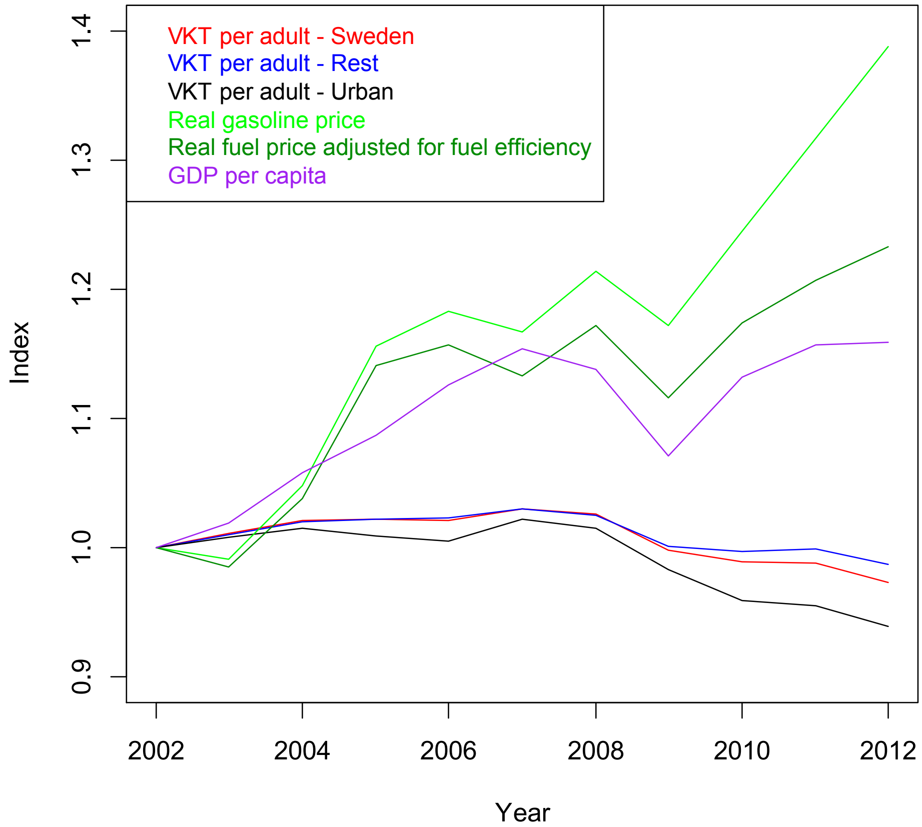

Figure 1: Trends in VKT per adult for total Sweden, urban areas and the rest of Sweden 2002-2012. Trends in GDP per capita, gasoline price and fuel price adjusted for fuel efficiency.

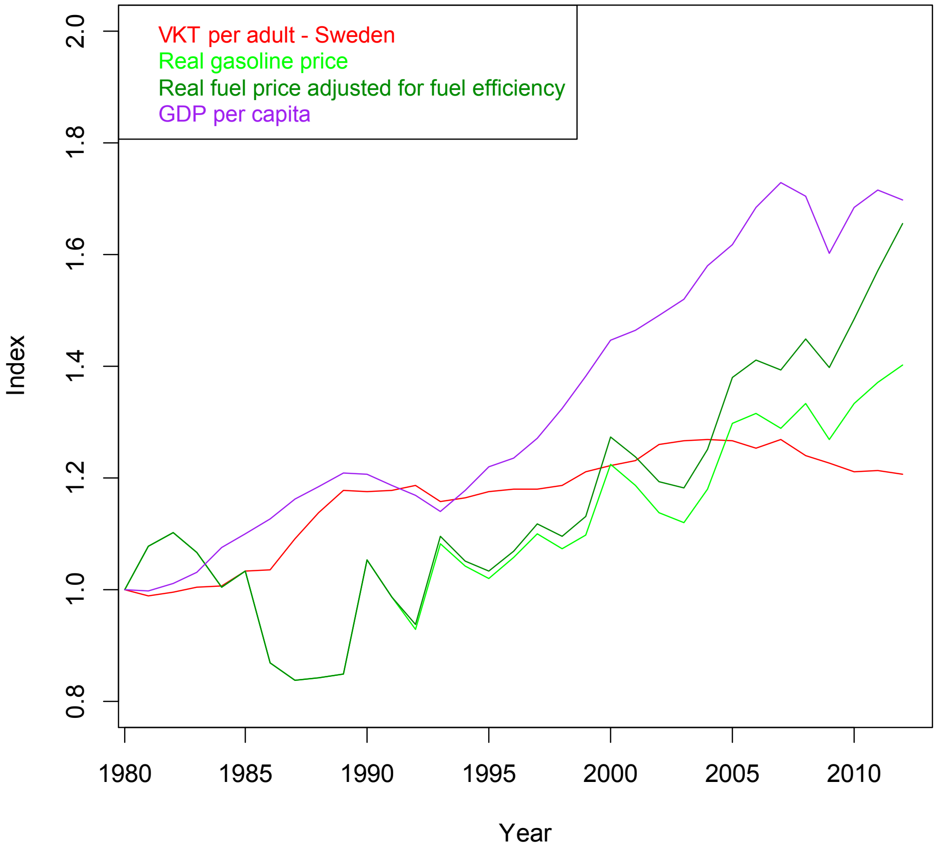

Figure 2: Trends in VKT per adult for total Sweden, GDP per capita, gasoline price and fuel price adjusted for fuel efficiency 1980-2012.

Table 2: Descriptive statistics - urban areas

year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Adult population	1.78	1.79	1.79	1.81	1.83	1.86	1.89	1.93	1.96	1.99	2.03
VKT (10^{10})	1.35	1.37	1.38	1.39	1.4	1.44	1.46	1.44	1.43	1.45	1.45
Cars registered (10^6)	0.9	0.9	0.91	0.91	0.93	0.94	0.95	0.95	0.96	0.98	0.99
VKT per adult (10^4)	0.76	0.77	0.77	0.77	0.76	0.78	0.77	0.75	0.73	0.73	0.71
cars per adult	0.5	0.5	0.5	0.5	0.51	0.5	0.5	0.5	0.49	0.49	0.49
VKT per car (10^4)	1.51	1.52	1.53	1.52	1.51	1.54	1.54	1.51	1.49	1.48	1.45

Table 3: Descriptive statistics: rest of Sweden

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Adult population (10^6)	4.68	4.7	4.72	4.74	4.76	4.8	4.84	4.88	4.91	4.94	4.96
VKT (10^{10})	4.34	4.4	4.47	4.49	4.52	4.59	4.6	4.53	4.54	4.58	4.54
Cars registered (10^6)	3.06	3.07	3.1	3.13	3.18	3.19	3.21	3.22	3.26	3.3	3.33
VKT per adult (10^4)	0.93	0.94	0.95	0.95	0.95	0.96	0.95	0.93	0.92	0.93	0.92
cars per adult	0.65	0.65	0.66	0.66	0.67	0.66	0.66	0.66	0.66	0.67	0.67
VKT per car (10^4)	1.42	1.43	1.44	1.44	1.42	1.44	1.43	1.41	1.39	1.39	1.36

4 URBANIZATION AND IMMIGRATION

The fact that the average VKT per adult is lower in the urban areas than elsewhere is common and does not apply to Sweden alone. It has led some to argue that urbanization is the driver behind a declining VKT per adult on the national level. However, the decline in VKT per adult within both urban areas and the rest of the country shows that urbanization is at least not the only driver of the national decline in VKT per adult between 2007 and 2012. In fact, had the average VKT per adult remained constant within each municipality between 2007 and 2012, the national VKT per adult would have declined by only 0.5% due to the increased share of the adult population residing in the urban areas. Over a longer time, urbanization, in the sense that an increasing share of the adult population reside in urban areas, might be more important.

Immigration could also be important for VKT per adult trends in the longer run, because of its present contribution to both urban population growth and license-holding gaps, possibly also to income and unemployment gaps. License-holding, average income and employment level are all lower among Swedish residents born abroad than among Swedish-born residents. The divide by foreign-born and others in terms of license-holding is most pronounced among women (see Figure 3), in particular low-educated women (Statistics Sweden, 2014b). The majority of the foreign-born population resides in the urban areas. Presently, about one-third of the middle-aged adult residents of Stockholm County were born abroad.

The Stockholm suburbs Södertälje, Sundbyberg and Upplands Väsby experienced the strongest decline in VKT per adult of all municipalities since 2007 (about a 10% decline), even more than the city municipalities of Stockholm and Gothenburg (about a 6% decline). These municipalities have among the highest shares of foreign-born residents in Sweden, but also good public transport access and below-average incomes. Less driving among foreign-born residents and high immigration into urban areas could be contributing factors to the decline or slower increase in VKT per adult in urban areas in a longer time perspective. In the perspective of five-ten years, demographic changes should, however, be less important. An even more plausible explanation of the strong declining trend of VKT per adult in municipalities with a high share of foreign-born inhabitants in this shorter-term perspective is that the GDP per capita and fuel price elasticities are higher among foreign-born residents due to higher price- and income-sensitivity and possibly also better public transport accessibility. This assumption will be tested in the estimation of the models defined in Section 4.2, applying data on the municipality level. Table 4 describes how the variables applied in Section 4.2 vary across municipalities.

In this paper. we do not explicitly explore the impact of license holding. However, there was a substantial decline in young adults' license holdings during the 1990s, but since 2000 this has stabilized among new generations of young adults born in Sweden (BilSweden, 2014). A decline in the license-holding among young adults born in Sweden; therefore, does not explain the changes in VKT per adult over the recent decade.

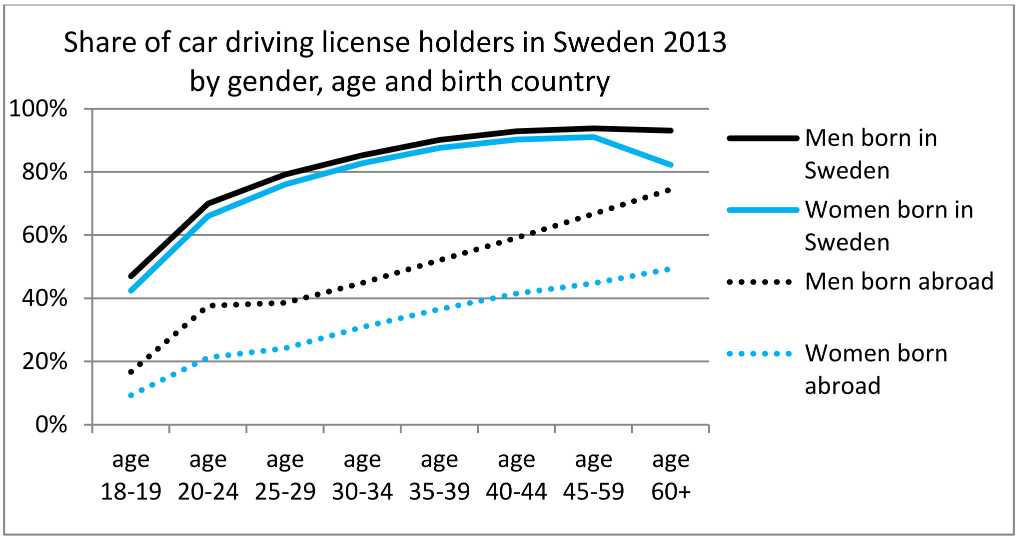

Figure 3: Based on Swedish driving license register from Statistics Sweden

Table 4: Descriptive statistics, distribution across Swedish municipalities.

	Min	1st Quartile	Median	Mean	3rd Quartile	Max	Min
Foreign-born (%)	0.040	0.079	0.101	0.115	0.136	0.398	0.040
Public transport supply (vehicles per day and km^2)	0.005	0.098	0.215	1.457	0.755	62.250	0.005
Density (inhabitants per km^2)	0.243	12.15	26.43	141.1	75.13	4708	0.243
Median income (SEK per adult and year)	191900	221100	232100	235900	244700	328000	191900

5 MODEL SPECIFICATION

In this section, we define a set of models that explores the systematic relationships between the VKT per adult and GDP per capita and fuel price. We set out by estimating a constant elasticity OLS model for the period 2002-2012 with the most accurate data from car inspections. In the first set of models, we use the VKT per adult aggregated to the national level as dependent variable. After that, we evaluate the extent to which this model explains the trend in VKT per adult since 1980 based on the trends of fuel prices and GDP per capita.

Since it is clear from the descriptive statistics in the previous section that the elasticities of VKT per adult with respect to fuel price and the GDP per capita are larger in the urban areas than in the rest of Sweden, we also estimate different OLS models for urban areas and the rest of Sweden.

In section 5.2, we define a fixed effect model estimated on the 2002-2012 data broken down by the municipality level, such that each observation represents one year and one municipality. In this model, we let the elasticity depend on four municipality-specific explanatory variables. The fixed effect controls for time-invariant unobserved municipality-specific variables.

5.1. OLS model

We apply a linear regression model to estimate a constant-elasticity relationship between the dependent variable log of VKT per adult, denoted y_t, observed for t ∈ {2002, 2003, .., 2012} and the explanatory variables, X_t, including the log of GDP per capita, x_{t1}, and the log of the real fuel consumer price, x_{t2}, in year *t*. The model takes the form

$$y_t = \beta_0 + \beta_1 x_{t1} + \beta_{i2} x_{t2} + \epsilon_{nt}, \quad (1)$$

where ϵ_{nt} is a normally distributed random error. This model is estimated separately for total Sweden, urban areas only, and the rest of Sweden. This model assumes that drivers adapt their driving behavior within one year after a price or income change. We have also tried to include a lagged effect of both fuel price change and GDP per capita, to account for lagged behavioral adjustments. The lagged effect is captured by the average fuel price (or the GDP per capita) of the previous three years.

5.2. Fixed effects model

The fixed effects model explores the extent to which the elasticities of VKT per adult with respect to GDP per capita and fuel price depend on four municipality-specific variables: average income level 2002-2012, share of the population born outside Sweden in 2012, public transport supply in 2012, and population density in 2012. The dependent variable is still the log of VKT per adult, denoted y_{mt}, which is observed for municipality *m* and year *t*. The explanatory variables, X_t, include, as before, the log of GDP per capita, x_{t1}, and the log of the real fuel price, x_{t2}, in year *t*. We allow the elasticities, β_1 and β_2, to depend on the explanatory variables Y_m, including the four municipality-specific explanatory variables

$$\beta_{pm} = \gamma_{p0} + \gamma_{p2} y_{m2} + \cdots + \gamma_{p5} y_{m5}. \qquad p = 1,2 \quad (2)$$

The model takes the form

$$y_{mt} = \beta_{1m} x_{t1} + \beta_{2m} x_{t2} + \alpha_m + \epsilon_{mt}, \quad (3)$$
$$m = 1, \ldots\ldots, M; \qquad t = 2002, \ldots\ldots, 2012,$$

where α_m is the individual specific fixed effect and ϵ_{nt} is a normally distributed random error. The fixed effects model allows for arbitrary dependence between (time independent) unobserved municipality-specific variables and the controls X_t, which, if present, would violate the assumption of an OLS model and bias the results. The controls cannot include municipality-specific variables because they would be perfectly correlated with the municipality-specific constants, α_m.

6 RESULTS

6.1. OLS model

The estimation results of models (1) are shown in Table 5. Since the model is estimated in the log-log space, the elasticities equal the corresponding parameters for fuel price and GDP per capita, respectively. The models in the top rows are estimated assuming that the drivers adjust their behavior with respect to real fuel price. The models shown in the bottom rows are estimated based on the assumption that the drivers also take into account that new cars have become more fuel-efficient over the period we model. In this model, the dependent variable is fuel price adjusted for fuel efficiency, as shown in Figure 1. The models using unadjusted fuel price have higher r-squared. These models have also fewer parameters because the lagged effect of fuel price and GDP per capita is only significant in the models estimated using the fuel price adjusted for fuel efficiency.

Although we do lack conclusive evidence, a plausible explanation for the unadjusted fuel price resulting in better model fit is that the drivers focus on the fuel price, which is more visible, is concrete and stays constant across driving conditions, than the adjusted price, at least in the time perspective of a couple of years (around half of the increase in fuel efficiency occurred in the two years 2010 to 2012). Many drivers have no clear perception of the fuel efficiency, in particular not for driving in city traffic, where it varies substantially. Another tentative explanation relates to the finding that, as we will see in section 6.1, the price and income elasticity varies with income. Newer cars and more fuel-efficient cars, which are more expensive, tend to be bought by companies and households that are less price-sensitive than the average driver. More efficient cars are also more expensive, so if the driver includes the cost of purchasing a more expensive but efficient vehicle because it will pay off in the longer run, while taking into account the distance that she will drive, it is unclear what the driving cost really is in a time perspective of a couple of years.

Since the model fit, for whatever reason, is higher assuming the real fuel price, we focus more closely on these models in the rest of this paper. The elasticity of fuel price on VKT per adult as estimated for total Sweden is well in line with the short-run elasticities reported in the previous literature (reviewed in the introduction). The elasticity with respect to GDP per capita lies between those reported for the long-run and the short-run elasticities in the previous literature. The elasticities are also well in line with the Swedish National Transport model Sampers (Maria Börjesson, 2014), which is estimated based on cross-sectional National Travel Survey data from 1994-2001. This model produces an average fuel price elasticity of -0.33 for regional travel and GDP per capita elasticity of 0.7. Hence, these results show no signs of trend break in terms of increased elasticities in recent past years. In line with our a priori expectation, fuel price elasticity is lower (in absolute value) outside of urban areas.

The model using the adjusted fuel price has the same short-run elasticities, approximately -0.3 for fuel price, but produces a larger fuel price elasticity in the long run. The total elasticity adds up to -0.52, which is also consistent with previous literature.

The r-squared for the base model is around 80 percent, indicating that the GDP per capita and fuel price explain most of the change in VKT per adult. This is also indicated by the close match between the modeled trends in VKT per adult and the actual trends depicted in Figure 4. Due to the few data points, however, the high r-squared does not provide strong evidence that the fuel price and GDP per capita explain most of the variation in the VKT per adult trends. To further evaluate the models and the elasticities they produce, we validate the model estimated on the total VKT per adult for Sweden using the data from 1980-2012.

The model for total Sweden is applied to calculate the trend in VKT per adult 1980-2012, based on the trends in real fuel consumer price and GDP per capita within this time period. Figure 5 compares the model-calculated VKT per adult with the real outcome of VKT per adult 1980-2012. The comparison shows that the model computed and the real trend match well back to 1990, and before 1988. The fit is, however, poorer between 1988 and 1990, because the increase in fuel price in the late 1980s did not reduce driving to the extent that the model suggests. Hence, either the fuel price elasticity was lower at the time than later on, or there are errors in the measurement of the VKT per adult from the 1980s.

Figure 4 also depicts the trend produced by the model estimated on the fuel price adjusted for fuel efficiency. That model also fits the trend of measured VKT per adult back to 1990 reasonably well, but the fit for 1988-1990 is worse.

Together these results suggest that the changes in fuel prices and GDP per capita explain most of the decline in VKT per adult 2002-2012 and that the elasticities estimated over the time period 2002-2012 are not substantially different from the elasticities prevailing since the 1980s.

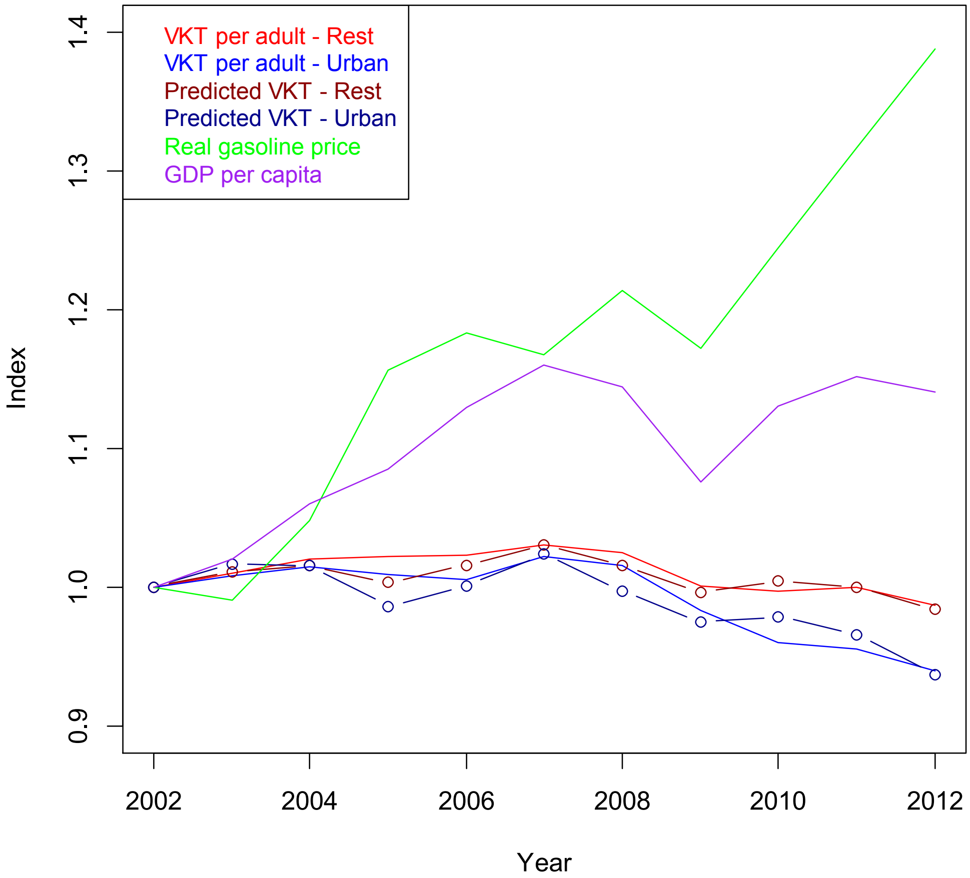

Figure 4: Model prediction compared to observation trend in VKT per adult 2002-2012.

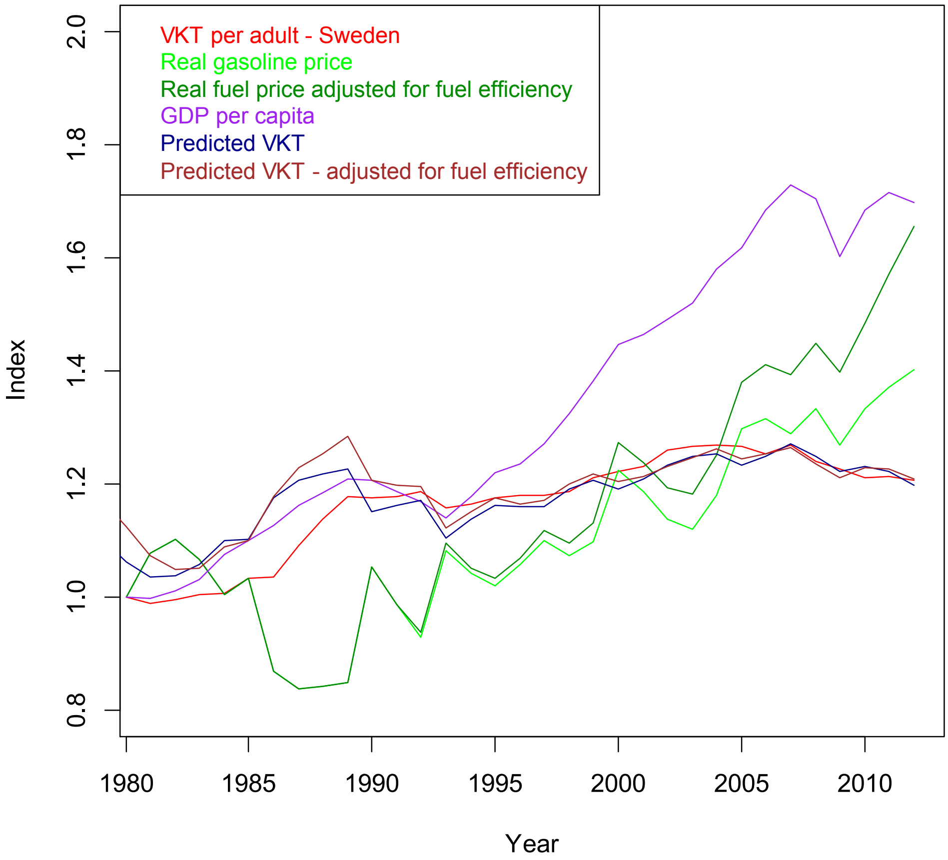

Figure 5: Model validation. Prediction compared to observation years 1980-2012. The index for predicted VKT per adult is computed by dividing predicted VKT per adult by the observed VKT per adult in 1980.

Table 5: Model estimation result.

	Total Sweden		**Rest of Sweden**		**Urban Areas**	
Observations	11		11		11	
R-squared	0.77		0.77		0.82	
Variable	Estimate	t stat	Estimate	t stat	Estimate	t stat
Base model						
Intercept	0.89	1.52	1.22	2.68	0.46	0.57
log(BNP per capita)	0.52	4.35	0.44	4.76	0.63	3.81
log(Gas)	-0.30	-5.24	-0.23	-5.10	-0.45	-5.68
Model where fuel cost is adjusted for efficiency						
R-squared	0.68		0.73		0.70	
	Estimate	t stat	Estimate	t stat	Estimate	t stat
Intercept	1.21	1.46	1.47	2.54	0.81	0.65
log(BNP per capita)	0.55	2.92	0.47	3.57	0.69	2.46
log(Gas adjusted for fuel efficiency)	-0.30	-2.23	-0.22	-2.33	-0.50	-2.45
log(Lag gas adjusted for fuel efficiency)	-0.22	-2.25	-0.18	-2.74	-0.27	-1.88

6.2. The fixed effects model

Table 6 shows the result of the fixed effects model defined by (2) and (3), using data broken down by municipality and year. All insignificant variables in Y_m are taken out from the final models. The model for all Sweden shows that the VKT per adult elasticity with respect to fuel price increases (in absolute terms) with higher density, large public transport supply, and higher share of the population born outside of Sweden. The underlying hypothesis is that the former two variables increase the elasticities because higher density and larger public transport supply facilitate a switch from car use to alternative travel modes (both public transport and slow modes) and a switch to destinations closer to the origin in order to reduce travel distances. The higher elasticity among foreign-born is likely due to higher cost sensitivity, arising from both higher unemployment and lower incomes in this group.

The VKT per adult elasticity with respect to GDP per capita increases with higher density and higher public transport supply, presumably for the same reason as they increase the elasticity with respect to fuel price. As expected, higher average income reduces the elasticity with respect to GDP per capita due to lower cost sensitivity.

The model for the rest of Sweden is similar to that for total Sweden (since 260 of the 287 municipalities are located outside the urban areas). Within the urban areas, only the share of foreign-born is significant, because the data set is small and because the share of foreign-born correlates strongly with income, density and public transport provision in the cities.

The models are applied to calculate the fuel price and GDP per capita elasticity for each municipality. According to the model for urban areas, the fuel price elasticities range between -0.36 and -0.63 in the urban municipalities, and the GDP per capita elasticity is 0.51. Outside the urban areas the fuel price elasticities range between -0.10 and -0.64, and the GDP per capita elasticities range between 0.25 and 0.99. These numbers suggest that there is also a substantial variation in elasticities within urban areas and the rest of Sweden, due to income and price sensitivity and due to availability of different modes and destinations.

Table 6: Fixed effects model GDP per capita and fuel price elasticities for VKT per adult.

	Total Sweden		**Rest of Sweden**		**Urban Areas**	
	Estimate	t stat	Estimate	t stat	Estimate	t stat
# Municipalities	287		260		27	
# Observations	3157		2860		297	
R-Squared	0.246		0.206		0.547	
log(GDP Capita)	1.44	13.66	0.93	6.72	0.51	8.10
log(Gas)	-0.07	-6.03	-0.09	-6.83	-0.28	-5.55
Density log(Fuel)	-0.00013	-6.77	0.00	-4.11		
Foreign born · log(Gas)	-0.77	-9.48	-0.21	-2.19	-0.91	-4.35
Density · log(GDP Capita)	0.00013	2.84	0.0007	3.73		
Income · log(GDP Capita)	-1.07	-10.20	-0.59	-4.20		

PT · log(Gas)			-0.03	-3.18		
PT · log(GDP Capita)	0.01	2.15				

Income is positively correlated with density (income level is on average higher in denser municipalities) and higher density increases the (in absolute terms) VKT per adult elasticity with respect to fuel price and GDP per capita. It is, therefore, essential to control for population density when estimating the impact of income on the elasticities. If not, the results indicate that (absolute) elasticities increase with income. However, when controlling for population density, as in the analysis above, the results are reversed. Figure 6 demonstrates how the reduction in VKT per adult increases with higher average income, although the model in Table 5, which controls for the higher (absolute) elasticities in denser municipalities, shows that elasticity with respect to GDP per capita in fact reduces with income.

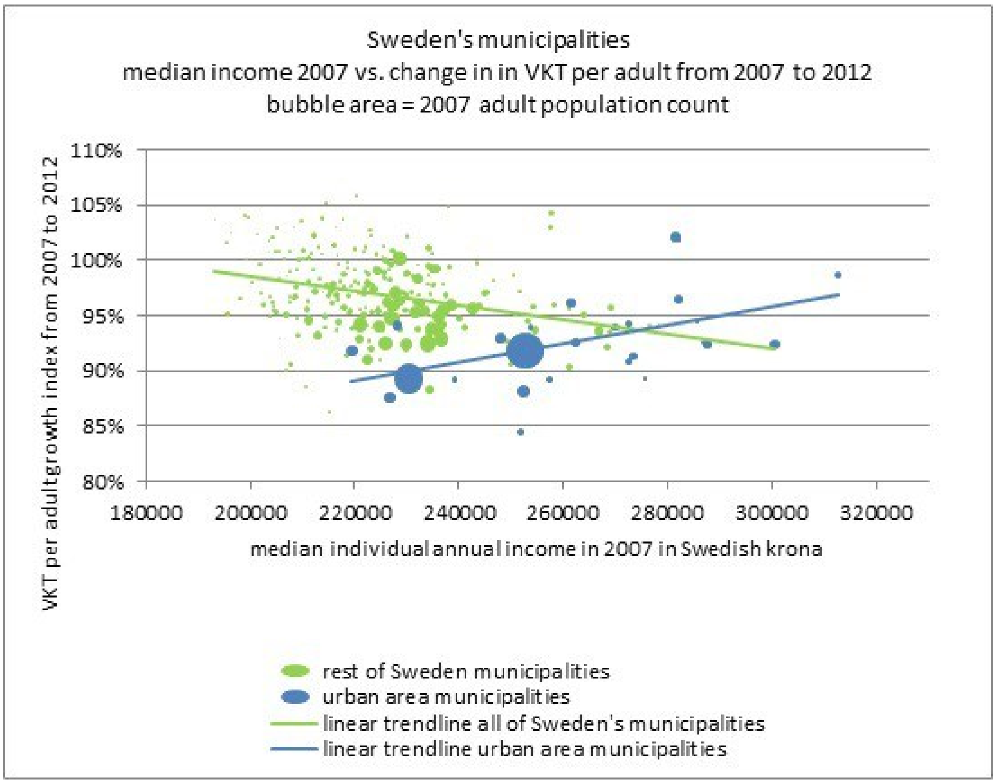

Figure 6: Change in VKT per adult from 2007 to 2012 by median income by municipality

7 CONCLUSIONS

This study suggests that much of the observed rise and fall in Swedish VKT per adult from 2002 to 2012 can be explained by trends in fuel price and GDP per capita. The fuel price and GDP per capita elasticities estimated on aggregate data from 2002 to 2012 are well in line with those estimated in the literature and those produced by the Swedish national transport forecast model estimated on cross-section data. These elasticities can also reasonably well reproduce the VKT trend per adult back to 1980. Hence, based on the decline in VKT per adult observed between 2008-2012, it is at least too early to draw conclusions about a substantial trend break in the preferences for driving on the aggregate level.

On the other hand, our analysis also shows the limitation of analyses of driving behavior on the aggregate level. We find substantial variation among municipalities in terms of elasticity of VKT per adult with respect to fuel price and GDP per capita. These elasticities vary among municipalities depending on public transport supply, population density, share of foreign-born inhabitants and the average income level. The elasticities are in general higher among urban populations and in municipalities with high densities, high public transport supply, low average income and high share of foreign-born. Hence, due to urbanization and high immigration to Sweden, the elasticities might increase in the long run. Moreover, low elasticity of car use with respect to GDP per capita among the high income population indicates a saturation effect in the highest income segment, implying that income growth among high-income people might have a small effect on VKT per adult. This is relevant in forecasting, given that income gaps have been widening in Sweden over the last decade (Statistics Sweden, 2014a) and most income growth has been accruing to people with high incomes.

Transport modeling is based on the underlying assumption that preferences stay constant over time. From this perspective, it is reassuring that most of the variation in VKT per adult in 2002-2012 can be explained by elasticities in fuel price and GDP per capita. However, the economic downturn and fast increase in fuel prices after 2008 was difficult to predict. This demonstrates the importance of accurate predictions of economic growth and fuel prices for accurate transport forecasts. Our findings are consistent with the finding of De Jong et al. (2007), suggesting that uncertainty in input variables is a larger source of errors in transport forecasting than is uncertainty in model parameters. Long-term predictions of immigration, land-use and settlement patterns may, thus, all add to the uncertainty over a longer time horizon.

From a policy perspective, the key message from this study is that a combination of driving cost increases, densification and mixed land-use as well as good public transport supply is effective in reducing car use. Moreover, due to the inevitable remaining uncertainty in transport demand and car-use forecasts, it is advisable to aim at solving problems that already exist and generate benefits instantly rather than aiming at solving problems in the transport system that are anticipated to arise according to the transport forecast. It is also advisable to evaluate transport and land-use policies not only by their social return but also by their flexibility and resilience to changes in demand, technology, financing, and priorities.

Our analysis shows that there is no need, or at least that it is too early, to assume changes in fundamental attitudes towards car driving to explain VKT trends 2002-2012 in Sweden. However, this does not necessarily imply that changes in preferences, attitudes, lifestyles, and social trends are not relevant or important for behavioral changes. On the contrary, it seems likely that changes in life-style factors to a large extent are induced by economic factors in the long run and the two sets of factors are, therefore, inseparable. Many long-term lifestyle trends, such as urbanization and more young people acquiring university education, seem to be driven by economic incentives. This suggests that adaptations in terms of shifts in lifestyles, preferences, and attitudes reinforce the effectiveness of economic incentives in the long run and possibly also increase their acceptability. There are indications in the transport sector that this is the case. For instance, travelers adapt more easily to economic incentives over a longer time (Börjesson et al., 2011; Goodwin et al., 2004) and are often not even aware that they change their attitudes and behavior in response to economic incentives, as found in the evaluation of the Stockholm congestion charge (Eliasson, 2014).

Our findings from Sweden are likely transferable to some European countries with similar conditions in fuel prices, incomes, urbanization levels and public transit supply.

REFERENCES

BilSweden. (2014). http://www.bilsweden.se/statistik/korkort, website accessed on 05.12.2014.

Blow, L., and Crawford, I. (1997). The distributional effects of taxes on private motoring. IFS Commentaries C065. Institute for Fiscal Studies: London, UK.

Börjesson, M. (2014). Forecasting demand for high speed rail. *Transportation Research Part A: Policy and Practice*, *70*, 81–92. doi:10.1016/j.tra.2014.10.010

Börjesson, M., Eliasson, J., Hugosson, M., and Brundell-Freij, K. (2011). The Stockholm congestion charges - four years on. Effects, acceptability and lessons learnt. *Accepted for Publication in Transport Policy*.

Brons, M., Nijkamp, P., Pels, E., and Rietveld, P. (2014). A Meta-analysis of the Price Elasticity of Gasoline Demand. A System of Equations Approach. *Econometrica*, *82*(2), 705–30.

Dahl, C. A. (2012). Measuring global gasoline and diesel price and income elasticities. *Energy Policy*, *41*, 2–13. doi:10.1016/j.enpol.2010.11.055

Dahl, C., and Sterner, T. (1991). Analysing gasoline demand elasticities: a survey. *Energy Economics*, *13*(3), 203–210. doi:10.1016/0140-9883(91)90021-Q

De Jong, G., Daly, A., Pieters, M., Miller, S., Plasmeijer, S., and Hofman, F. (2007). Uncertainty in traffic forecasts: literature review and new results for The Netherlands. *Transportation*, *34*, 375–395.

Eliasson, J. (2014). The role of attitude structures, direct experience and reframing for the success of congestion pricing. *Transportation Research Part A: Policy and Practice*, *67*, 81–95. doi:10.1016/j.tra.2014.06.007

Espey, M. (1998). Gasoline demand revisited: an international meta-analysis of elasticities. *Energy Economics*, *20*(3), 273–295. doi:10.1016/S0140-9883(97)00013-3

Fox, J., and Hess, S. (2010). Review of Evidence for Temporal Transferability of Mode-Destination Models. *Transportation Research Record: Journal of the Transportation Research Board*, *2175*(-1), 74–83. doi:10.3141/2175-09

Goodwin, P. (2013). Peak Travel, Peak Car and the Future of Mobility. Discussion Paper No. 2012-13, Prepared for the Roundtable on Long-Run Trends in Travel Demand 29-30 November 2012.

Goodwin, P., Dargay, J., and Hanly, M. (2004). Elasticities of road traffic and fuel consumption with respect to price and income: a review. *Transport Reviews*, *24*(3), 275–292.

Goodwin, P., and Van Dender, K. (2013). "Peak Car" — Themes and Issues. *Transport Reviews*, *33*(3), 243–254. doi:10.1080/01441647.2013.804133

Graham, D., and Glaister, S. (2004). Road traffic demand elasticity estimates: a review. *Transport Reviews*, *24*(3), 261–274.

Grimal, R., Collet, R., and Madre, J.-L. (2013). Is the Stagnation of Individual Car Travel a General Phenomenon in France? A Time-Series Analysis by Zone of Residence and Standard of Living. *Transport Reviews*, *33*(3), 291–309. doi:10.1080/01441647.2013.801930

Hanly, M., Dargay, J., and Goodwin, P. (2002). Review of Income and Price Elasticities in the Demand for Road Traffic. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.192.1387andrep=rep1andtype=pdf

HBEFA. (2014). The Handbook Emission Factors for Road Transport (HBEFA), Version HBEFA 3.2. http://www.hbefa.net/e/index.html.

Headicar, P. (2013). The Changing Spatial Distribution of the Population in England: Its Nature and Significance for "Peak Car." *Transport Reviews*, *33*(3), 310–324. doi:10.1080/01441647.2013.802751

Millard-Ball, A., and Schipper, L. (2011). Are We Reaching Peak Travel? Trends in Passenger Transport in Eight Industrialized Countries. *Transport Reviews*, *31*(3), 357–378. doi:10.1080/01441647.2010.518291

OECD. (2013). Executive Summary. In OECD/ITF, Long-run Trends in Car Use. OECD Publishing/ITF.

Santos, G., and Catchesides, T. (2005). Distributional Consequences of Gasoline Taxation in the United Kingdom. *Transportation Research Record: Journal of the Transportation Research Board*, *1924*, 103–111. doi:10.3141/1924-13

SIKA. (2004). Transportarbetets utveckling. SIKA PM 2004:7. Trafikanalys. http://www.trafa.se/sv/Statistik/Transportarbete/.

Statistics Sweden. (2014a). http://www.Statistics Sweden.se (Accessed on 2014-06-12).

Statistics Sweden. (2014b). Hushållens ekonomiska standard (The economic standard of households). Report BV/EV - pm 2014 (2). http://www.Statistics Sweden.se.

Sterner, T., and Dahl, C. A. (1992). Modelling transport fuel demand. In T. Sterner (Ed.), *International Energy Economics* (pp. 65–79). Springer Netherlands. Retrieved from http://link.springer.com/chapter/10.1007/978-94-011-2334-1_5

Swedish Transport Administration. (2014a). Handbok för vägtrafikens luftföroreningar. http://www.trafikverket.se/Privat/Miljo-och-halsa/Halsa/Luft/Dokument-och-lankar-om-luft/Handbok-for-vagtrafikens-luftfororeningar/. http://www.trafikverket.se.

Swedish Transport Administration. (2014b). Prognos för Personresor 2030. Trafikverkets basprognos 2014 report. (Prediction for passenger travel 2030.). http://www.trafikverket.se.

Wadud, Z., Graham, D. J., and Noland, R. B. (2009). Modelling fuel demand for different socio-economic groups. *Applied Energy*, *86*(12), 2740–2749. doi:10.1016/j.apenergy.2009.04.011

Wadud, Z., Graham, D. J., and Noland, R. B. (2010). Gasoline Demand with Heterogeneity in Household Responses. *The Energy Journal*, *31*(1). doi:10.5547/ISSN0195-6574-EJ-Vol31-No1-3

World Bank. (2014). http://data.worldbank.org/indicator/EP.PMP.DESL.CD (Accessed on 2014-06-12).