The Economics of Low Emission Zones

Abstract

This paper develops a methodology for assessing costs and benefits of Low Emission Zone (LEZ), and use data for an empirical estimate of the magnitude of the effects. We apply the methodology to Stockholm, providing a unique opportunity of assessing these costs due to the micro data available from the congestion charging system, in terms of visiting frequencies to the inner city by vehicles type and age, and the driver's adaptations cost of refraining to go by car to the inner city (observed when the congestion charging levels were increased). Our key result is that costs (higher driving costs and carbon emissions due to impacts on the sales of new cars, and adaptation cost for existing diesel car owners) are approximately twice as high as the benefits (reduced air pollution and higher fuel tax revenues for governments revenue due to impacts on the sales of new cars). However, a LEZ for heavy trucks has the same benefit in terms of lower NOx exposure but much lower adaptation and environmental costs. A LEZ has a negligible effect on congestion.

Keywords: Diesel gate; low emission zones, environmental zones, CBA, internalization, congestion charges

1 INTRODUCTION

In 2015 the dieselgate scandal emerged, revealing that diesel cars' emissions of health damaging nitrogen oxides are multiple times above laboratory certified values. Since then, many cities are considering introducing or extending low emission zones (LEZ), banning vehicles with older emission standards. Because the primarily target is usually nitrogen oxide pollution, many would ban relatively young vehicles, while earlier European policies targeted primarily particle matter pollution (Wolff and Perry, 2010). For this reason, several recently announced LEZ policies in Europe ban substantial shares of the light vehicle fleet, mainly passenger cars and light goods vehicles, in addition to heavy vehicles. Still, no previous paper has consistently computed the social costs and distribution effects. The aim of this paper is to set up and define a methodology for computing the social benefits as well as the social cost of LEZ, and then apply the evaluation framework to a proposed LEZ in Stockholm.

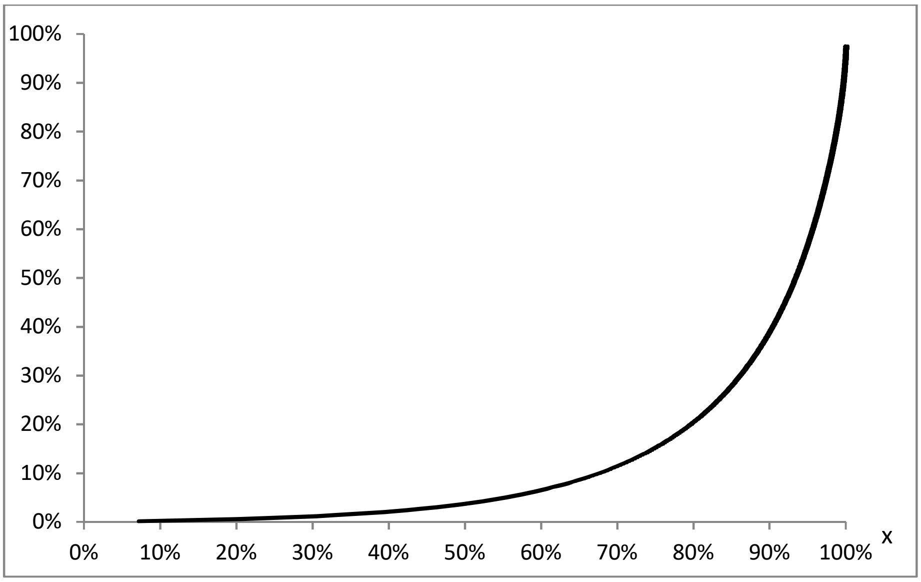
In March 2018, the Swedish national government defined emission standards for Swedish light vehicle LEZs and gave municipalities the right to introduce light LEZs from year 2020 onwards. The political majority in Stockholm proposed a policy banning light petrol vehicles below Euro 5 emission standard and light diesel vehicles below Euro 6 standard from driving in the LEZ. We assume that the emission class requirements and the spatial extent of the light vehicle LEZ will remain unchanged from year 2022 onwards.

2 AIR QUALITY AND CONGESTION WITHIN THE LEZ

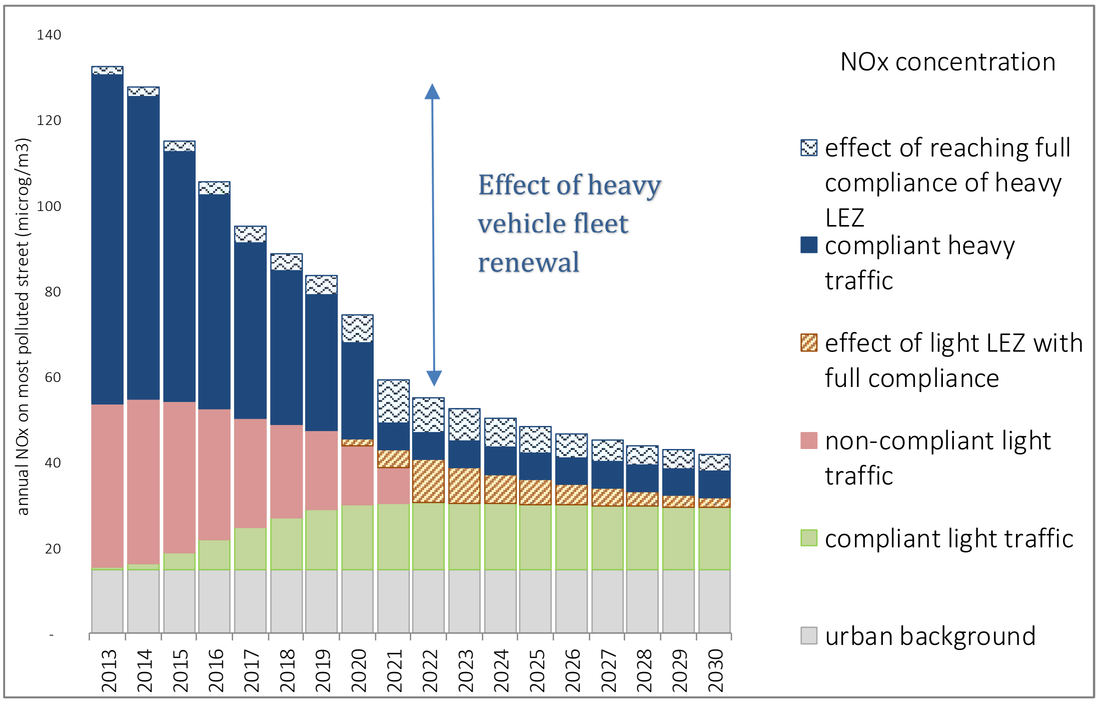
Surprisingly many unique vehicles visit Stockholm's inner city every year. One fourth of the Swedish light vehicle fleet (1.3 out of 5.3 million light Swedish vehicles), including 80% of Stockholm County's vehicle fleet, visit it at least once per year. In year 2022, approximately 30% of the unique visiting light vehicles and 21% of trips to the zone would be non-compliant with the LEZ policy. In subsequent years the number non-compliant vehicles and trips would reduce quickly, because of the natural renewal of the vehicle fleet. In 2030, only 5% of the trips to the zone would be non-compliant.

Most non-compliant light visiting vehicles only come to the inner city infrequently, particularly privately-owned cars. This is demonstrated by the cumulative share of all trips with light non-compliant vehicles to the LEZ made by the x share of non-compliant light vehicles with the lowest trip frequency to the LEZ (out of the total number of non-compliant trips entering the LEZ at least once a given year) shown below. For instance, a quarter of all non-compliant vehicles make 90% of all the visits to the LEZ by non-compliant vehicles (only this quarter of the vehicles visit the zone three times per month or more).

Only 2.2 percent of all visits to the zone are made by non-compliant vehicles vising the zone less than three times a month (23% of all of the unique visiting light vehicles). For this reason, we expect the LEZ to have no or only minor effects on traffic volume: those visiting the zone three times or more have strong incentives to incur the fixed cost of upgrading to a compliant vehicle.



The figure below shows how the sources of NOx changes over the years for Stockholm's most polluted inner-city street. The figure shows a quickly decreasing NOx contribution from heavy traffic, due to a growing share of heavy goods vehicles having Euro VI emission standard. This is mostly due to a natural renewal (the blue solid bars). The the LEZ for heavy traffic introduced 2021 speeds up the shift to Euro VI further in the zone (the dashed blue bars) but has a smaller impact than the natural renewal of the heavy vehicle fleet. The NOx contribution from light traffic also reduces due natural renewal of the car fleet (the apricot solid bars). Full compliance of the LEZ for light vehicles would reduce the annual NOx further by approximately 18 percent in 2022, declining to 7% in 2030 due to the natural renewal of the car fleet. Full compliance of the LEZ for heavy traffic would have approximately the same effect on the NOx emissions. However, the heavy traffic incudes only 18 000 unique vehicles visiting a given year, compared to 1.3 million unique light vehicles visiting the zone. Thus, a LEZ for heavy vehicles would reduce NOx to the same extent as a LEZ for light vehicles but impacting much fewer unique vehicles, implying lower adaptation and enforcement costs.



The changes in NOx pollution impacts mortality and the estimation of the benefits of this estimation involves three steps: First, the change in population weighted exposure by year t is estimated. This is calculated on a detailed geographic level based applying a transport model with high geographic resolution. Second, the relative risk for premature death is multiplied with the change in the population weighted exposure. Third, this is multiplied by the change in mortality and population size, yielding the number of statistical life years saved Δl_t by year t. We assume constant monetary present value per statistical life year at γ. The health benefit of the policy is valued at $\sum_t \gamma \, \Delta l_t$ which is 65 M€ (net present value).

3 CHANGES IN THE CAR FLEET COMPOSTION

Low emission zones can have greenhouse gas emission effects, and can also impact driving costs, because they impact the choices of vehicle type of consumers and firms buying new cars. Thereby, LEZ can impact emissions and driving costs over the full lifecycle of some vehicles. A new petrol car emits approximately 25% more carbon dioxide per kilometre than a diesel car of equal size (O'Driscoll et al., 2018), and uses approximately 40 % more fuel. Furthermore, Swedish legislation requires a larger and more rapidly increasing share of biofuel in diesel than in petrol.

To assess the impact on car sales of LEZ, we compare the observed car sales of different car types in 2018 with a forecast issued by Swedish Transport Analysis Agency in April 2017, just before the prominent media debate on a possible LEZ in Stockholm began.[1] The forecast was based on observed trends and decided policies at the time. The sales of new petrol cars increased 8 percentage point during 2018 compared to a forecast, and these petrol cars were replacing new diesel cars. Depending on the assumptions regarding when the sales of diesel car reverts towards the baseline forecast, we find

[1] The forecast already assumed the share diesel cars fall and are replaced by petrol cars, based on the trends after 2013 and 2015. Moreover, the argument is that the diesel engine requires a relatively expensive cleaning technology. Costs such as car manufacturers can instead add to the efficiency and hybridization of the gasoline engine.

that carbon emissions would increase by 4-7 million tons, which equals 25-47% of the carbon emissions by all road transport in Sweden in 2017. However, since the external costs are over-internalized for petrol cars and under-internalized for diesel cars, replacing diesel cars with petrol cars adds a social benefit of 1.1 Billion Euro (net present value). However, increased driving costs also implies a social loss (including reduced driving distances) for drivers of 651 M€. In total, changes in the car fleet implies a social benefit of 588 M€.

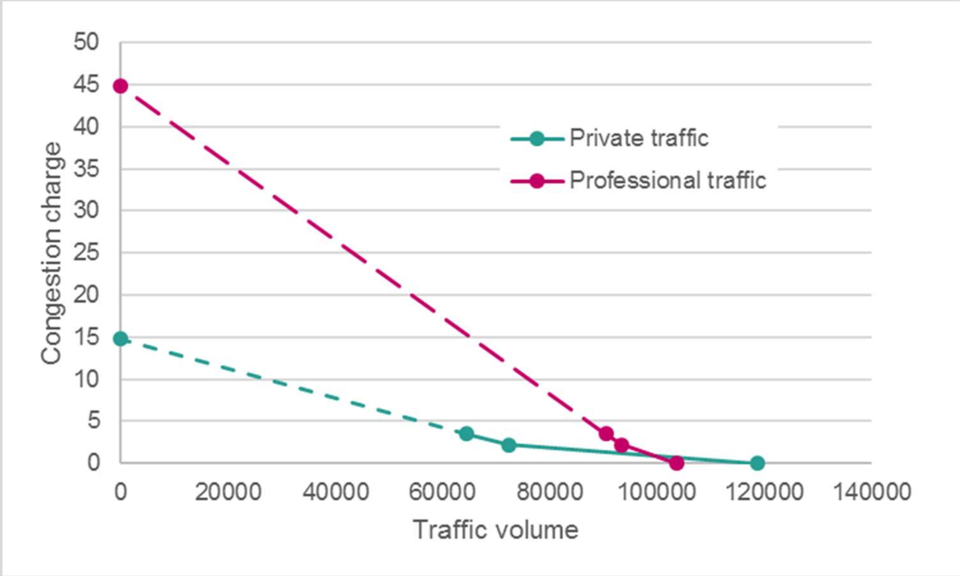
4 ADAPTATION COSTS OF CAR OWNERS

In this chapter we assess the magnitude of the welfare loss of the car drivers who are no longer allowed to enter the LEZ using two different methods. In the first subsection, we calculate this welfare loss using a demand curve based on how the Stockholm congestion charges changed traffic volumes. Assuming that this demand curve can be extrapolated (which is a strong assumption), we can calculate the drivers' welfare loss as the loss of Marshallian consumer surplus. We call this method the "on the road" approach, since the welfare loss is based on observations of traffic demand.

Introducing a LEZ will tend to decrease the demand for diesel cars and increase it for gasoline cars, which will affect the prices of used cars. This welfare loss is captured by the "on the road" approach. The two methods should give the same result, if consumers have perfect information, if there are no uncertainty regarding changes in the geography or banned vehicles over time, and if there is no marketing effect of negative publicity of diesel cars due to the zone. If this is not the case, they will not be the same.

4.1 Measuring welfare loss "on the road"

Stockholm introduced congestion charges in 2006 and the were increased in 2016. The diagram below shows how private and professional traffic volumes were changed by the congestion charges. When the charges were introduced (2006), private trips across the cordon during charged hours were reduced from 119 000 to 72 000, and profession trips from 104 000 to 93 000 (counting two passages across the cordon as a "trip"). The average charge per trip (two passages) was 2.17€. Assuming linear demand functions, the adaptation cost of the trips priced off the road would be 14.7 € for private trips and 44.7€ for professional trips. The average adaptation costs are therefore (14.7-3.51)/2= 5.58 € for private trips and (44.7-3.51)/2 = 20.6 € for professional trips. Assuming a linear demand curve rather than a convex is a strong assumption and will tend to underestimate the welfare loss.



The table shows the estimated number of trips to or within the LEZ zone with non-compliant vehicles by type and the average adaptation cost. From this, the final column computes the total adaptation cost, summing to 966 M€. These figures assume 4% discount rent and that the value of time increased by 2% a year.

	Average adaptation cost €/trip	Trips banned by an LEZ 2022-2030, Million	Total adaptation cost for banned vehicles, M€
Private cars	5.6	56	315
Cars owned by firms	20.6	14	296
Light trucks	20.6	17	355
Total		88	966

4.2 Measuring welfare loss "on the car market"

Introducing a LEZ can be expected to impact prices and demands on the used-car market. In this section, we show that these effects can be ignored, provided that the "on the road" approach can be used to accurately reflect drivers' welfare loss; if so, no additional losses or benefits should be added. However, using reactions on the car market opens up an alternative way to assess drivers' welfare loss – one which also captures other effects that may be relevant, such as uncertainties about the future regulations.

To explore this, we introduce a simple model. Assume that drivers' can be represented by a representative consumer owning D_1 diesel cars and D_2 petrol cars. Let q_1 and q_2 be the quality of the services delivered by petrol and diesel cars, respectively, and p_1 and p_2 be the prices of cars on the second-hand market. The representative consumer has a money-metric[2] utility function u, where utility is derived from using the other cars and from other goods (x), and a fixed income Y. The representative consumer chooses the number of cars to own by solving the following utility maximization problem:

$$\max_{D_1, D_2, x} u(D_1 q_1, D_2 q_2, x)$$

[2] This eliminates income effects, since this is not our focus here.

s.t. $D_1 p_1 + D_2 p_2 + x = Y$

This allows us to represent the service quality of the cars explicitly in the utility function, and hence to analyse what happens when service quality changes, for example due to an LEZ. Let $v(q_1, q_2, p_1, p_2)$ be the indirect utility function resulting from solving the utility maximization problem. Let N_1 and N_2 be the supply of diesel and petrol cars. The total social welfare W is then the sum of the representative consumer's welfare and the revenues from used-car sales:

$$W = v(q_1, q_2, p_1, p_2) + p_1 N_1 + p_2 N_2,$$

A LEZ banning the use of diesel cars in an area decreases the service quality of diesel cars. Call this change in service quality dq_1. In equilibrium, this leads to changes in car prices dp_1 and dp_2. Assume that the numbers of diesel and petrol cars are constant in the short run, so the price changes are determined to make the new demand meet the same supply as before. We obtain the total welfare effect of all of these changes dW by total differentiation of W,

$$dW = \frac{\partial v}{\partial q_1} dq_1 + \frac{\partial v}{\partial p_1} dp_1 + \frac{\partial v}{\partial p_2} dp_2 - N_1 dp_1 - N_2 dp_2 =$$

Note that this uses that car supply is assumed to be constant, i.e. $\frac{\partial N_1}{\partial p_1} = 0$ and $\frac{\partial N_2}{\partial p_2} = 0$. From Roy's identity we get $\frac{\partial v}{\partial p_i} = -D_i$, and we get

$$dW = \frac{\partial v}{\partial q_1} dq_1 - D_1 dp_1 - N_2 dp_2 + N_1 dp_1 + N_2 dp_2 = \frac{\partial v}{\partial q_1} dq_1,$$

since demand equals the constant supply $D_i = N_i$ by assumption. This shows that all the second-order effects on prices and demands vanish from the total welfare change, leaving only the first-order effect $\frac{\partial v}{\partial q_1} dq_1$: the decrease in indirect utility from the lowered service quality. Provided that the "on the road" approach above accurately captures this decrease in service quality, there is thus no need to take the second-order effects on prices into account when calculating the total welfare effects.

However, the total welfare effect *can* be calculated using observed price changes, providing an alternative to the "on the road" calculation. To explain how, separate the market reactions into two steps indexed A and B, where A is the direct effects on the diesel car demand, and B is the subsequent effects caused by substitution to petrol cars, which in turn causes rebound effects on the diesel car market. First, the decrease in diesel car service quality dq_1 induces a negative shift in the demand curve for diesel cars. Assuming (for the moment) that the petrol car price is fixed, this induces a price drop for diesel cars dp_1^A that reflects the average market valuation of the decreased service quality, since the supply of used diesel cars is fixed. The welfare loss of this change is hence the price drop multiplied by the number of diesel cars (this can be shown formally using that $\frac{\partial v}{\partial q_1} dq_1 = \frac{\partial v}{\partial p_1} \frac{\partial p_1}{\partial q_1} dq_1 = -D_1 \frac{\partial p_1}{\partial q_1} dq_1 = -D_1 dp_1^A$).

Second, substitution from diesel to petrol cars increases the demand for petrol cars. Since the supply of petrol cars is fixed, this increases the petrol car price, which causes a rebound effect increasing the diesel demand and hence the diesel price somewhat again. Call these second-order price effects dp_1^A and dp_2^B. These price changes, however, cancel out when calculating total welfare, which can be seen by total differentiation of the total welfare W:

$$dW^B = \frac{\partial v}{\partial p_1} dp_1^B + \frac{\partial v}{\partial p_2} dp_2^B + N_1 dp_1^B + N_2 dp_2^B =$$
$$= -D_1 dp_1^B - D_2 dp_2^B + N_1 dp_1^B + N_2 dp_2^B = 0$$

In words, the price increase for gasoline cars is just a windfall profit for gasoline car owners, paid for by switching diesel owners.

The diesel price effect observed on the market in equilibrium is $dp_1 = dp_1^A + dp_1^B$ (note that $dp_1^A < 0$, $dp_1^B > 0$ and $dp_1 < 0$). The total welfare loss, however, is equal to $D_1 dp_1^A$. Since the second price change dp_1^B is negative, replacing the unobserved dp_1^A with the observed diesel price change dp_1 will underestimate the true welfare loss. But we know from above that the windfall profits of the gasoline owners $N_2 dp_2$ corresponds to the second-order loss for diesel owners. So subtracting the amount that gasoline owners have gained from the (negative) quantity $D_1 dp_1$ gives us the total welfare loss.

The table shows the fleet size and price drop of all Swedish diesel and petrol cars, as reported by used car dealers in Sweden. As can be seen, the price loss is larges for diesel cars from 2012 and younger.

	Car fleet size diesel N_1	Price change, diesel (€) dp_1	Total loss (M€) $N_1 dp_1$	Car fleet size petrol N_2	Price change, petrol (€) dp_2	Total loss (M€) $N_2 dp_2$
2004	0	0	0	219 318	0	0
2005	33 115	0	0	247 527	-207	-51
2006	61 325	-544	-33	219 318	229	50
2007	113 564	-544	-62	184 301	261	48
2008	97 165	-444	-43	114 515	-655	-75
2009	91 183	-266	-24	87 926	235	21
2010	154 282	-1395	-215	108 228	-731	-79
2011	195 153	2355	460	106 452	227	24
2012	195 419	-1827	-357	90 565	-684	-62
2013	175 438	-455	-80	102 851	590	61
2014	188 034	-972	-183	116 525	-21	-2
2015	206 400	-1516	-313	131 576	3554	468
2016	201 057	-1017	-204	155 320	1289	200
2017	191 068	-936	-179	157 557	336	53
Sum			-1234			655

Using the equations and method from above we find that the total welfare loss, measured by price reactions on the car market, is $N_1 dp_1 - N_2 dp_2 = -1234 - 655 = -1889$ M€. This is almost twice the effect as measured ”on the road”, which is in line with our expectations.

5 CBA SUMMARY

Adding up the consumer surplus, non-internalized external cost and adaptation cost assuming the "car market approach" we find a total loss of 1.4 Billion € in net present value. The cost (higher driving costs and carbon emissions due to impacts on the sales of new cars, and adaptation cost for existing diesel car owners) are approximately twice as high as the benefits (reduced air pollution and higher fuel tax revenues for governments due to impacts on the sales of new cars).

	Present value in 2018, M€		
	Of which		**Sum**
Consumer Surplus			**-651**
Fuel taxes and value added tax		-1 642	
Non-internalized external cost			**1 104**
Fuel taxes and value added tax		1 642	
Carbon emissions		-673	
Air pollution		135	
In central Stockholm direct effect	65		
In Sweden impacts of the car fleet	70		
Adaptation cost			**-1 889 (-966)**
Total			**-1 436 (-513)**